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LIFE HISTORY OF HABROCYTUS MEDICAGINIS, A RECENTLY DESCRIBED PARASITE OF THE CHALCIS FLY IN ALFALFA SEED

By THEODORE D. URBAHNS,

Entomological Assistant, Cereal and Forage Insect Investigations, Bureau of Entomology

INTRODUCTION

The following account of *Habrocytus medicaginis* Gahan is the result of observations concerning its parasitism upon *Bruchophagus funebris* How. inhabiting alfalfa seed (*Medicago sativa*). The observations were begun in the fall of 1912 and continued into the year 1915. The field observations and collections extended over several of the States west of the Rocky Mountains. The laboratory studies were conducted at Glendale and Pasadena, Cal.

DISCOVERY OF THE PARASITE

This new hymenopterous parasite, *H. medicaginis*, was first found by the writer on September 28, 1912. Several specimens had emerged from alfalfa seeds infested by *B. funebris* collected at Yuma, Ariz., on August 30. Adults of the parasite continued to emerge from the seeds until October 15 of the same year.

The parasite was again reared on November 4, 1912, from infested alfalfa seeds taken at Chino, Cal., on September 24; from this lot of seeds individuals continued to emerge until July 12, 1913. Additional alfalfa seeds collected at Tulare, Cal., on October 1, 1912, yielded this species at different times between June 11, 1913, and April 9, 1914.

Alfalfa seeds dissected on March 6, 1913, at Glendale, Cal., showed larvæ of this species feeding upon the dead larvæ of *B. funebris*. Some of the parasite larvæ were reared to the adult stage as early as April 22.

The writer made many collections of alfalfa seeds throughout the different alfalfa seed-growing districts between the Rocky Mountains and the Pacific coast during the seasons of 1913 and 1914. From these seeds adults of *H. medicaginis* emerged as follows: Dos Palos, Cal., October 11, 1913; Stockton, Cal., June 16, 1914; Brawley, Cal., June

17, 1914; Red Bluff, Cal., September 23, 1914; Pendleton, Oreg., September 23, 1914; Twin Falls, Idaho, September 23, 1914; Blackfoot, Idaho, September 29, 1914; Gunnison, Utah, October 10, 1914; Bishop, Cal., April, 1915; Manti, Utah, June 5, 1915; Aberdeen, Idaho, June 16, 1915; and Nephi, Utah, June 16, 1915. The total rearings of this parasite brought the number of adults up to several hundred specimens from these different localities. Figure 1 shows the known distribution of the insect.

In recent years various members of the Bureau of Entomology, and others, have reared *B. funebris*, together with miscellaneous insects emerging from both clover and alfalfa seeds. These specimens were examined and it was found that *H. medicaginis* was reared from alfalfa seed pods infested by *B. funebris* as follows:

August 12, 1908, Mesilla Park, N. Mex., by C. N. Ainslie.
———— 1908, Chico, Cal., by R. McKee.
———— 1910, Sacramento, Cal., by O. E. Bremner.
September 24, 1910, Wellington, Kans., by E. O. G. Kelly.
———— 1910, Wellington, Kans., by T. H. Parks.
September 9, 1910, Wellington, Kans., by H. Osborn.
———— 1912, Cavite, S. Dak., S. Halvardgaard.
———— 1913, Newell, S. Dak., C. N. Ainslie.
———— 1914, Salt Lake City, Utah, by T. R. Chamberlin.

CLASSIFICATION AND DESCRIPTION

H. medicaginis belongs to the hymenopterous superfamily Chalcidoidea, family Pteromalidae, subfamily Pteromalinae. Specimens reared

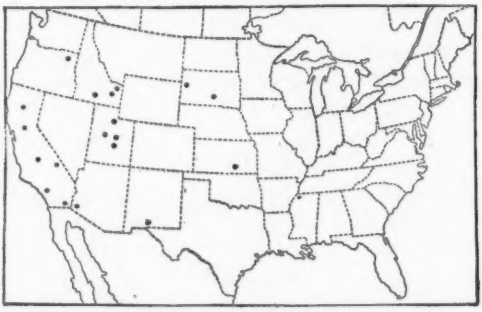


FIG. 1.—Map of the United States, showing the known distribution of *Habrocytus medicaginis*.

by the writer from *B. funebris* in alfalfa seeds at Yuma, Ariz., were described by Gahan as a new species.[1]

The description of the female is as follows:

Length about 1.7 mm. Head and thorax closely punctate, the punctures on the medial portion of the mesoscutum slightly larger than those on the scapulæ and scutellum; antennæ with two ring-joints; pedicel and first funicle joint, excluding

[1] Gahan, A. B. Descriptions of new genera and species, with notes on parasitica Hymenoptera. *In* Proc. U. S. Nat. Mus., v. 48, p. 163. 1915.

the ring-joints, about equal; following funicle joints a little longer than the first and a trifle longer than broad; viewed from in front the head is broader than long, the clypeal region with converging striæ and a deep median sinus on the anterior margin; viewed from above the head is slightly broader than the thorax, narrow anteroposteriorly, the occiput slightly concave, the ocellocular line longer than the lateral ocellar line, the lateral ocellar line not equal to half the postocellar line; pronotum strongly transverse with a sharp margin anteriorly; propodeum short, without a neck, with a median carina and lateral folds, the region between the lateral folds more or less distinctly wrinkled and with a fovea-like depression at the base and another at the apex of the fold; the region outside the lateral folds is usually more faintly sculptured with indistinct lines; propodeal spiracles elliptical; marginal and postmarginal veins subequal, the stigmal one-third shorter; abdomen conic-ovate, about as long as the head and thorax and nearly smooth, the dorsal segments beyond the first with very faint transverse lines. Head and thorax æneous; antennæ brown, the scape slightly paler beneath; wings hyaline; all coxæ æneous like the thorax, all trochanters and femora black with an æneous tinge; tibiæ and tarsi usually reddish yellow, the former often brownish except at apex; apical joint of all tarsi dark; abdomen polished aeneous.

LIFE HISTORY OF THE HOST

The host insect (*B. funebris*) of *H. medicaginis* completes its entire life development within the growing seeds of alfalfa, red clover (*Trifolium incarnatum*), and wild species of Medicago. After reaching maturity the adult eats a hole through the seed wall and through the wall of the seed pod to make its escape. *B. funebris* may pass through from one to four or five generations in a single season.

METHOD OF STUDYING THE PARASITE

The fact that *H. medicaginis* completed its entire development within the unbroken walls of an alfalfa seed made it necessary for the writer to dissect many seeds under a microscope and remove this parasite in its different stages for special study. Small parasite larvæ removed from seeds were placed singly upon a larva of their host. The host and parasite were then placed in a small cavity made in a 7-mm. cork and covered by a glass vial (Pl. 4, fig. B). A most satisfactory method of observing one of these larvæ in its development was to place it upon a larva of *B. funebris* and keep both host and its parasite in a cavity made between two layers of sheet cork. The upper layer of cork could then be removed to expose the parasite larva.

STAGES OF HOST SHOWING PARASITISM

H. medicaginis is parasitic upon the larval stage of its host with possibly a few exceptions. Microscopic dissections of many infested alfalfa seeds showed 77 larvæ of this species, each feeding externally upon the larval stage of its host (Pl. 4, fig. D). This parasite was in no case found to be attacking the pupa of *B. funebris*. Only a single parasite is able to develop upon its host within the walls of a single infested alfalfa seed.

The parasite larva in completing its development usually destroys the larva of its host with the exception of the head and mandibles. If two parasites chance to be upon a single host, one dies before development continues for any length of time.

APPEARANCE OF THE INSECT IN THE FIELDS

Throughout the Southwestern States the first adults make their appearance in the fields as early as March and April, simultaneously with the development of seed pods upon the earliest alfalfa plants. Out of nearly 100 hibernating larvæ kept under observation at the laboratory, 23 emerged as adults in March, 39 in April, 8 in May, and 4 in June. They attack the first generation of larvæ of *B. funebris* infesting the earliest isolated plants and increase throughout the summer in accordance with the abundance of their host insects.

OVIPOSITION

The adult female, frequently seen to be active on the blossoms and soft green seed pods in the alfalfa fields, is apparently able to locate the pods in which seeds have previously been infested by *B. funebris*. She selects her position upon the green pod directly over an infested seed. During oviposition the head is slightly elevated and the antennæ are held directly forward. The tip of the abdomen is lowered almost to the surface of the seed pod. The ovipositor is forced through the soft walls of the pod and into the watery seed. It is necessary for the egg of the parasite to be placed within the infested seed and upon the larva of its host in order that the newly hatched parasitic larva may secure food for its development.

THE LARVA

DEVELOPMENT

For several hours after emerging from the egg, the larva of the parasite may move about on its host without feeding, but when it once begins to attack its host and take food, its development follows rapidly. The writer's observations show that a growing larva of this species may completely destroy its host and become fully developed within a minimum period of five or six days after taking its first food.

DORMANT PERIOD

When the parasite larva has completed its development and consumed all of its available food, a period of rest frequently follows. The occurrence and duration of this resting period depends upon the moisture and temperature conditions to which the seed is subjected. A larva of *H. medicaginis* completing its growth within a moist seed of a green and growing pod will almost invariably transform to the pupal stage at once and emerge as an adult in due time, but if the infested alfalfa seed has

become dried from the hot desert winds before the parasitic larva has completed its development, a prolonged resting period may follow. This period may vary from a few weeks to a year. With combined moisture and a warm temperature the insect resumes its development toward the formation of the pupal stage.

DESCRIPTION

The larva is grublike and almost white in color and averages 1.6 mm. in length when fully developed. It is cylindrical in shape and rounded anteriorly and posteriorly. Head medium-sized and slightly bilobed. Mandibles almost invisible. It has a small inconspicuous tubercle on each eye lobe. There are 13 body segments of approximately equal length, except the first two, which are slightly longer; segmentation medium. Body skin usually slightly wrinkled, but sometimes smooth, glossy, and free from pubescence. Anal segment divided into a dorsal and a ventral lobe. Three fine setæ on dorsal lobe (Pl. 4, fig. C).

LENGTH OF LARVAL STAGE

The length of the larval stage depends greatly, as has been previously stated, upon the resting period following the development of the larva. A small newly hatched larva began feeding upon its host under observation on April 23. It showed noticeable growth from day to day, and by April 27 it had completely killed its host. On May 5 the larva transformed to the pupal stage. Another newly hatched larva dissected from a green alfalfa seed began feeding upon its host on September 5 and by September 7 the host was killed. The larva was apparently fully developed by September 11. Others removed from alfalfa seeds in August did not pupate until the following April. The minimum length of the larval stage as observed by the writer is normally about 12 days. The maximum length is a year or more.

PREPUPAL FORM

Just before entering the pupal stage the larva of *H. medicaginis* discharges an excessive amount of excrement. This is followed by a lengthening of the anterior body segments and the shaping of the pupa within the larval skin. The prepupal form requires two or three days unless retarded by unfavorable conditions.

THE PUPA

FORMATION

Pupation takes place after the pupal form has developed within the larval skin. The larval skin breaks along the dorso-anterior margin and is slowly worked back until the newly formed pupa is exposed.

DESCRIPTION

The newly formed pupa is white with salmon-colored eyes and ocelli; before transforming to the adult stage it becomes almost black in color. It averages 1.8 mm. in length. The head and tip of abdomen are bent slightly forward. The wing pads, legs, and antennæ, folded close to the body, are visible through the thin pupal skin (Pl. 4, fig. E).

LENGTH OF PUPAL STAGE

The length of the pupal stage varies greatly even in midsummer. This stage requires about 10 days under favorable field conditions in midsummer. Under laboratory conditions approximating out-of-door temperatures the pupal stage varied from 10 to 52 days, the long pupal stages being recorded in the months of March and April.

Larvæ, after hibernating through the winter, pupated in the spring and showed the following average period in the pupal stage: In March, 23 pupæ averaged 14 days; in April, 39 averaged 23 days; in May, 8 averaged 21 days; and in June, 4 averaged 18 days.

ADULT

The adult (Pl. 4, fig. A), upon emerging from the thin pupal skin, finds itself completely inclosed within the alfalfa seed and within the seed pod. It at once gnaws its way out, escaping by the small irregular opening which it makes.

CHOICE OF HOST PLANTS

H. medicaginis was not found to be present as a parasite of *B. funebris* when the latter infested the seed of red clover. This was true even where the red clover was taken near alfalfa fields and *H. medicaginis* was known to be present.

RELATIVE PROPORTION OF SEXES

Some localities from which this species was reared showed apparently no males, while in other localities a few males were found. The proportion of males is, however, very small to that of the females. Reared adults were counted to get the proportion of sexes. It was found that 270 of these were females and 9 were males. This showed a ratio of 1 male to 30 females.

SEASONAL HISTORY

In western Arizona and southern California *H. medicaginis* appears in the adult stage as early as the month of March. It is in its greatest abundance during July and August on irrigated alfalfa fields. On drier lands, where the seeds are subjected to desert conditions, many of the larvæ are driven to an early dormant period and the adults become less abundant in the hot months. Under extremely variable conditions there are from one to at least four generations in a single season. One larva

removed with its host from an alfalfa seed collected on December 19, 1913, transformed to the pupal stage in May, 1915, and emerged as an adult on June 2, 1915. On the other hand, a newly hatched larva of this species was placed upon its host on April 22, entered the pupal stage on May 5, and emerged as an adult on May 19. Another newly hatched larva placed under observation on September 5 had developed, pupated, and emerged as an adult by September 24. Infested alfalfa seeds which were collected on October 1, 1912, showed an adult of *H. medicaginis* emerging as late as April 9, 1914. These observations show that a period of from about 30 days to 1 year, and almost 2 years in exceptional cases, may be required for the completion of a single generation.

HIBERNATION

H. medicaginis hibernates in the larval stage within the infested alfalfa seeds which remain on the standing alfalfa, or on the ground when winter approaches. The undeveloped larvæ and those still in the pupal stage are usually killed by the first severe frost. In the mild climate of southern California occasional individuals of this species hibernate in the pupal stage. Nearly 100 larvæ of *H. medicaginis* were removed from their natural inclosure within the alfalfa seeds and placed in cavities between two layers of sheet cork. Of these larvæ 74 lived throughout the winter, entering the pupal stage in the months of March, April, and May at Glendale, Cal.

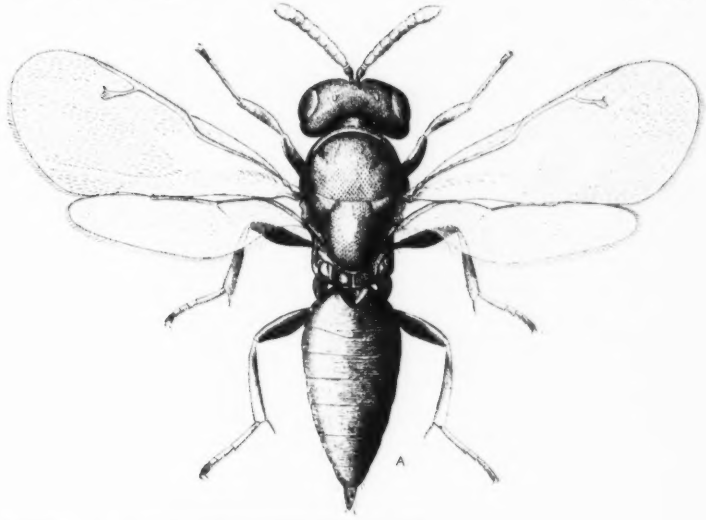
RATE OF PARASITISM

While this species is generally distributed throughout the alfalfa seed-growing districts of the United States, the rate of parasitism is not so large as might be expected. The comparative rearings of *H. medicaginis* and their host (*B. funebris*) show parasitism by *H. medicaginis* in several localities to be about as follows: Corcoran, Cal., 0.8 per cent; Tulare, Cal., 2.8 per cent; Chino, Cal., 2.8 per cent; and Yuma, Ariz., 4.9 per cent.

PLATE 4

Habrocytus medicaginis:

Fig. A.—Adult.
Fig. B.—Cages for rearing parasite larvæ.
Fig. C.—Larva.
Fig. D.—Larva destroying its host larva.
Fig. E.—Pupa.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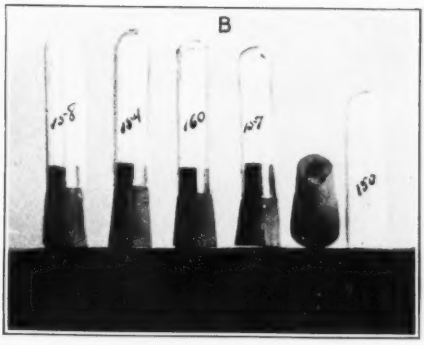
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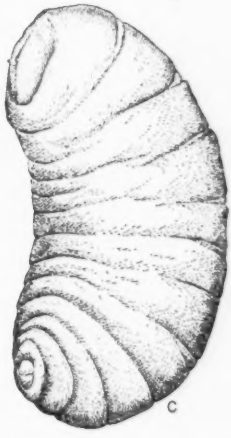
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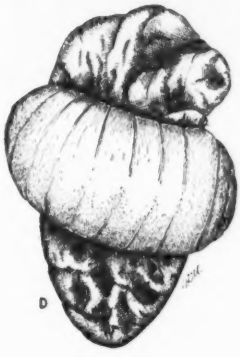
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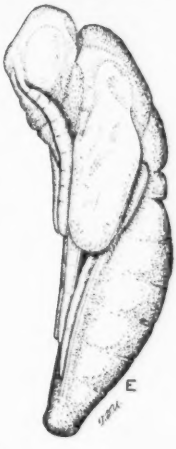
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DAILY TRANSPIRATION DURING THE NORMAL GROWTH PERIOD AND ITS CORRELATION WITH THE WEATHER

By LYMAN J. BRIGGS, *Biophysicist in Charge, Biophysical Investigations*, and H. L. SHANTZ, *Plant Physiologist, Alkali and Drought Resistant Plant Investigations, Bureau of Plant Industry*

This paper deals with the daily transpiration of a part of the crop plants included in the water-requirement experiments at Akron, Colo., in 1914 and 1915.[1] The principal objects of the measurements were the determination of (1) the march of transpiration during the growth period, and (2) the extent to which the daily transpiration is correlated with various weather factors.

EXPERIMENTAL METHODS

The plants were grown in galvanized-iron pots, containing about 115 kgm. of soil and provided with tight-fitting covers with openings for the stems of the plants. The annular space between the cover and the stem of each plant was sealed with a plastic wax. Direct evaporation from the soil was thus avoided and the loss of water limited to transpiration.[2]

Twenty-two crops were included in the daily weighings in 1914 and 23 crops in 1915. Each crop was represented by six pots of plants (Pl. 5) weighed independently. The weighings were made with an accuracy of 0.1 kgm. by means of a spring balance checked before and after each series of weighings against a standard weight of 130 kgm. The balance and weighing device are shown in Plate 6. The daily weights served also as a basis for determining the quantity of water to be added daily to each pot to insure an adequate water supply.

In differentiating between the transpiration of consecutive days it is desirable that the weighings be made at a time when the plants are losing very little water. Automatic records show that the transpiration is at a minimum just before sunrise.[3] The daily weighings, which required the time of three men for an hour, were accordingly begun in the morning as soon as there was light enough to work and completed before the transpiration response to sunlight had set in.

[1] Acknowledgment is gratefully made of the efficient and valued assistance of Messrs. R. L. Piemeisel, F. A. Cajori, P. N. Peter, J. D. Hird, G. Crawford, R. D. Rands, A. McG. Peter, H. W. Markward, H. Shattyn, and T. R. Henault at Akron in 1914 and 1915. Mr. W. H. Heal has also aided very materially in the reduction of the measurements.

[2] Briggs, L. J., and Shantz, H. L. The water requirement of plants. I.—Investigations in the Great Plains in 1910 and 1911. U. S. Dept. Agr. Bur. Plant Indus. Bul. 284, p. 9. 1913.

[3] ——— ——— Hourly transpiration rate on clear days as determined by cyclic environmental factors. *In* Jour. Agr. Research, v. 5, no. 14, p. 583–650, 22 fig., pl. 53–55. 1916. Literature cited, p. 648–649.

The transpiration of the plants in each pot, as determined by the weighings, was plotted daily as a check on the weighing and watering records. The daily transpiration of the first five crops of the 1914 series, traced directly from the original graphs, is shown in figure 1. These graphs are typical of the series and show the proportional response of the individual pots of plants to the fluctuations in weather factors. The daily transpiration of each crop is represented by the mean value of the six individual determinations, which minimizes slight errors in the weights of the individual pots, and abnormalities in the transpiration rate of individual plants. Inspection of figure 1 will show the close agreement of the individual determinations. While the plants in some pots of a given series transpire more than others, owing to differences in stand or size of the plants, the daily fluctuations are very nearly proportional.

The weather factors measured included solar radiation, air temperature, wet-bulb depression, and wind velocity. These factors, as well as evaporation, were integrated for each day. The solar radiation and the wet-bulb depression were measured by differential thermographs and the air temperature by a standardized air thermograph. The wind velocity was recorded by an anemometer located 3 feet above the ground. The evaporation was measured by means of a shallow blackened tank 6,540 sq. cm. in area, exposed at the level of the plants, and also by means of a large tank 8 feet in diameter and 2 feet deep, with the water surface at the ground level.[1]

DAILY TRANSPIRATION AND THE DAILY INTENSITY OF THE WEATHER FACTORS DURING THE GROWTH PERIOD

MEASUREMENTS IN 1914

The daily transpiration of 22 crops grown in 1914 is given in Table I, the daily loss being expressed in kilograms per pot. The small grains were well established before the daily weighings were begun, and had lost during the previous month approximately 10 per cent of the total water transpired during the entire growth period. The daily weighings in the case of the other crops cover the entire growth period after the daily loss had reached one-tenth of a kilogram or more per pot.

[1] For a further description of the methods and apparatus employed, see Briggs and Shantz, op. cit., 1916, p. 584–585, 625; and Briggs, L. J., and Belz, J. O. Dry farming in relation to rainfall and evaporation. U. S. Dept. Agr. Bur. Plant Indus. Bul. 188, p. 17. 1910.

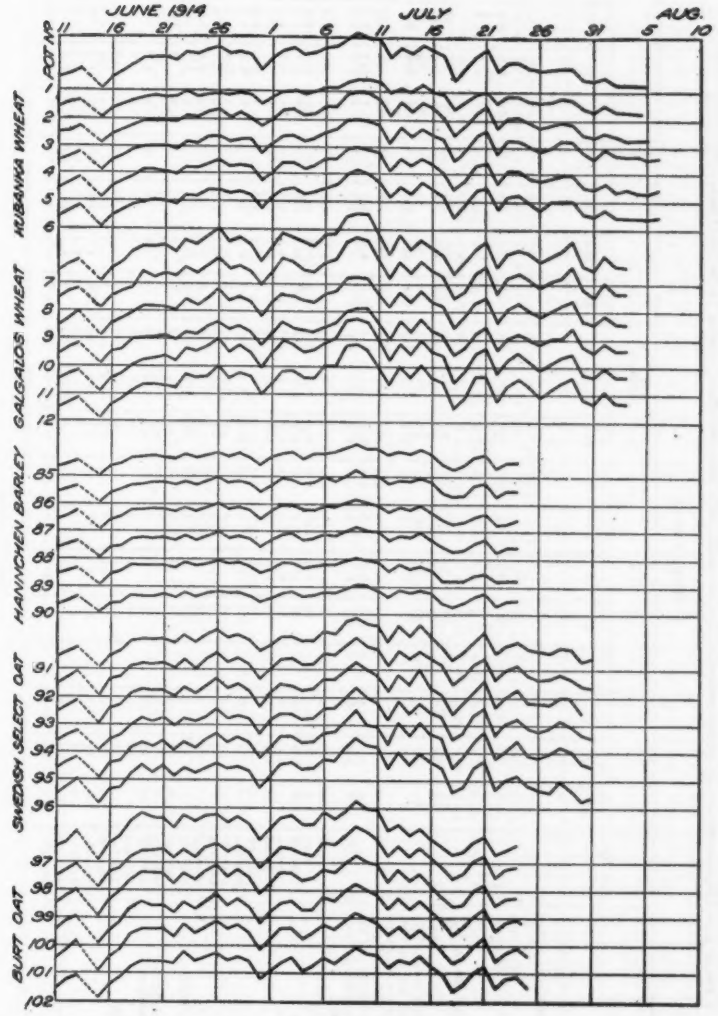


FIG. 1.—Graphs showing the daily transpiration from the individual pots of plants which constituted the first five sets in the transpiration measurements in 1914.

TABLE I.—*Measurements of environmental factors and daily transpiration, June 11 to September 25, 1914*

JUNE 11 TO 30

Item.	Pot No.	June.																			
		11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Evaporation (shallow tank), kgm. per sq. meter							6.76	8.81	11.86	13.15	10.86	12.20	10.58	12.17	10.79	12.05	17.67	16.65	12.84	12.14	5.54
Evaporation (deep tank) mm		3.10	5.08	6.40	3.36	2.37	4.65	4.90	5.87	7.39	7.57	8.46	7.47	6.15	6.71	8.69	13.75	5.87	8.36	8.18	3.33
Evaporation (deep tank) inches		.122	.200	.252	.132	.092	.183	.193	.231	.291	.298	.333	.294	.242	.264	.342	.541	.231	.329	.322	.131
Air temperature, max °C		26.1	30.6	32.2	24.4	16.1	22.2	26.7	31.7	32.8	30.6	32.2	26.1	33.9	31.7	33.9	29.4	29.4	33.3	28.3	21.1
Air temperature, min °C		10.6	8.9	12.8	11.7	9.4	11.7	12.8	11.7	14.4	11.7	12.8	13.3	13.3	14.4	13.9	8.3	7.2	7.8	6.7	7.8
Air temperature integrated, mean °C		19.4	20.0	23.3	17.8	13.3	17.2	20.0	23.3	23.9	21.7	22.8	20.0	23.9	22.8	26.1	20.0	19.4	21.1	20.0	15.0
Air temperature, max °F		79	87	90	76	61	72	80	89	91	87	90	79	93	89	93	85	85	92	83	70
Air temperature, min °F		51	48	55	53	49	53	55	53	58	53	55	56	56	58	57	47	45	46	44	46
Air temperature integrated, mean °F		67	68	74	64	56	63	68	74	75	71	73	68	75	73	79	68	67	70	68	59
Integrated radiation cal. per sq. cm.									959	974	890	934	984	1,011	1,032	836	1,069	1,006	890	1,006	553
Integrated wet-bulb depression deg. hrs.									178	182	167	173	145	187	118	176	264	203	212	162	84
Wind velocity miles per hr.		8.0	7.7	1.3	6.9	3.8	6.0	3.8	2.3	7.5	5.1	6.4	5.8	4.4	5.2	6.3	12.7	3.7	5.3	8.3	7.1
Wind velocity meters per sec.		3.6	3.4	.6	3.1	1.7	2.7	1.7	1.0	3.4	2.3	2.9	2.6	2.0	2.3	2.8	5.7	1.7	2.4	3.7	3.2
Daily transpiration, kgm.:																					
Wheat, Kubanka	1–6	1.2	1.5	2.0	.....	.2	•1.1	1.6	2.1	2.5	2.6	2.5	2.3	3.0	2.8	3.3	3.4	3.0	3.2	3.0	1.8
Wheat, Galgalos	7–12	1.2	1.8	2.2	.....	.2	1.4	1,8	2.6	3.1	3.1	3.2	2.9	3.9	3.5	4.0	4.8	3.7	4.2	3.7	2.3
Oat, Swedish Select	91–96	1.1	1.6	2.2	.....	.2	1.4	1.7	2.8	3.3	3.0	3.2	2.6	3.3	2.8	3.5	4.0	3.2	3.6	3.1	1.8
Oat, Burt	97–102	1.3	2.0	2.6	.....	.2	1.5	2.2	3.3	3.9	3.8	3.8	3.1	4.1	3.5	4.1	4.5	3.7	4.2	3.6	2.1
Barley, Hannchen	85–90	1.0	1.3	1.7	.....	.2	1.0	1.2	1.8	1.8	1.9	1.9	1.7	2.1	1.7	2.0	2.3	2.0	2.1	1.8	1.1
Rye, spring	103–108	1.3	1.7	2.2	.....	.2	1.3	1.9	2.7	3.1	3.0	3.0	2.6	3.5	2.8	3.2	3.4	2.8	3.0	2.6	1.5
Cowpea	169–174	.1	.4	.6	.....	.1	.3	.5	.9	1.3	1.5	1.3	1.3	1.9	1.7	2.3	2.8	2.0	2.2	2.1	1.3
Lupine	175–180	.1	.4	.4	.....	.1	.2	.4	.7	.9	1.0	.7	.7	1.1	.9	1.2	1.3	1.2	1.3	1.2	.8
Millet, Kursk	181–186	.....	.2	.2	.....	.1	.0	.2	.5	.7	.9	.8	.8	1.4	1.2	1.6	2.0	1.7	1.9	1.6	.9
Millet, Siberian	187–192	.....	.2	.2	.....	.1	.0	.2	.5	.7	.9	.8	.8	1.5	1.2	1.8	2.4	1.9	2.0	1.7	1.0
Corn, Northwestern Dent	217–222	.2	.1	.5	.....	.1	.1	.3	.6	.9	1.0	.9	.8	1.5	1.3	1.6	2.1	1.7	2.0	1.7	.8
Corn, Algeria	238–242	.1	.0	.3	.....	.1	.0	.0	.2	.4	.5	.3	.3	.7	.5	.8	1.0	.9	1.0	.9	.5
Sorghum, Minnesota Amber	205–210	.0	.0	.1	.....	.1	.....	.0	.2	.3	.4	.2	.2	.6	.5	.7	1.0	.9	1.0	1.0	.5
Sorghum, Dakota Amber	211–216	.0	.0	.2	.....	.1	.....	.1	.2	.3	.4	.2	.3	.6	.6	.8	1.0	1.0	1.1	1.0	.6
Sudan grass	410–414	.1	.0	.2	.....	.1	.1	.0	.1	.2	.3	.0	.1	.3	.2	.3	.6	.6	.7	.6	.3
Sudan grass (in open)	319–323	.0	.0	.0	.....	.0	.0	.0	.0	.0	.2	.0	.0	.2	.0	.2	.2	.2	.3	.2	.2
Amaranthus	163–168	.2	.6	.8	.....	.1	.5	.8	1.3	1.5	1.5	1.3	1.1	1.5	1.2	1.4	1.5	1.3	1.4	1.1	.6
Alfalfa, E23–20–52	109–114	.0	.2	.2	.....	.1	.2	.3	.5	.7	.9	.8	.8	1.2	1.1	1.5	1.7	1.5	1.6	1.7	1.1
Alfalfa, E23	115–120	.0	.3	.3	.....	.1	.2	.4	.6	.8	1.0	1.0	.9	1.4	1.3	1.8	2.1	1.8	2.0	2.0	1.4
Alfalfa, E23 (in open)	295–300	.2	.2	.3	.....	.0	.2	.3	.6	.8	.9	.9	.8	1.4	1.2	1.6	1.8	1.6	1.8	1.6	1.2
Alfalfa, 162–98A	127–132	1.2	1.8	2.3	.....	.3	1.4	2.3	3.2	3.7	3.9	4.0	3.6	4.5	4.3	5.1	6.5	5.2	5.6	4.9	3.8

JULY 1 TO 22

Item.	Pot No.	July.																				
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Evaporation (shallow tank), kgm. per sq. meter		9.27	12.84	12.82	9.08	10.40	13.43	11.28	13.92	14.34	15.04	12.26	7.89	11.86	9.66	14.06	12.87	10.82	5.08	6.18	10.70	13.94	5.69
Evaporation (deep tank), mm		6.35	6.73	7.36	5.44	6.71	8.81	8.03	9.45	10.77	10.62	8.11	4.83	6.23	7.06	9.78	9.32	9.66	3.68	4.45	6.71	10.53	4.34
Evaporation.....inches		.250	.265	.290	.214	.264	.347	.316	.372	.424	.418	.319	.190	.245	.278	.385	.367	.380	.145	.175	.264	.414	.171
Air temperature, max. °C		25.6	28.9	30.0	28.9	31.1	31.1	30.6	34.4	33.3	33.9	33.9	33.9	33.3	32.8	35.0	27.2	27.2	22.2	25.0	31.1	32.2	22.2
Air temperature, min. °C		12.2	11.7	9.4	12.8	13.3	13.3	12.8	13.3	15.0	15.6	17.8	13.9	15.0	17.8	18.3	16.7	13.9	13.3	15.0	17.2	12.8	16.1
Air temperature, integrated mean.....°C.		18.9	20.6	20.6	21.1	22.2	21.1	21.1	23.9	23.9	25.0	26.1	22.8	25.0	24.4	26.1	21.1	19.4	17.2	20.0	23.9	22.2	17.8
Air temperature, max., °F.		78	84	86	84	88	88	87	94	92	93	93	93	92	91	95	81	81	72	77	88	90	72
Air temperature, min., °F.		54	53	49	55	56	56	55	56	59	60	64	57	59	64	65	62	57	56	59	63	55	61
Air temperature, integrated, mean.....°F.		66	69	69	70	72	70	70	75	75	77	79	73	77	76	79	70	67	63	68	75	72	64
Integrated radiation, cal. per sq. cm		875	914	974	822	860	929	939	974	1,008	932	951	613	879	743	890	774	754	605	719	979	875	716
Integrated wet-bulb depression.....deg. hr.		138	170	176	111	162	173	145	228	248	216	231	153	181	174	240	199	158	44	68	148	201	66
Wind velocity, miles per hr.		6.3	8.0	5.3	7.6	4.2	7.6	5.9	6.3	7.4	8.3	4.6	3.3	4.8	6.2	6.7	8.2	9.6	6.5	2.8	5.4	10.1	4.2
Wind velocity, meters per sec		2.8	3.6	2.4	3.4	1.9	3.4	2.6	2.8	3.3	3.7	2.1	1.5	2.1	2.8	3.0	3.7	4.3	2.9	1.3	2.4	4.5	1.9
Daily transpiration, kgm.:																							
Wheat, Kubanka	1–6	2.7	3.4	3.5	3.0	3.2	3.7	3.8	4.6	5.0	4.8	4.4	2.9	3.9	3.2	4.0	3.4	2.8	1.0	1.9	3.1	3.5	1.7
Wheat, Galgalos	7–12	3.4	4.5	4.3	3.7	3.6	4.4	4.7	6.2	6.4	6.1	4.6	3.0	4.5	3.4	4.5	3.5	3.1	1.0	1.8	3.4	3.9	1.6
Oat, Swedish Select	91–96	2.8	3.6	3.6	3.0	3.1	4.0	3.9	4.9	5.7	4.9	4.6	3.0	4.6	3.6	4.6	3.6	3.0	1.0	1.8	3.1	3.9	1.6
Oat, Burt	97–102	3.0	3.9	4.0	3.2	3.3	4.3	3.9	4.7	5.5	4.9	4.6	3.1	4.0	3.1	3.8	2.9	2.0	.8	1.3	2.4	3.0	1.0
Barley, Hannchen	85–90	1.7	2.2	2.2	1.7	1.9	2.2	2.1	2.5	2.8	2.5	2.4	1.7	2.1	1.9	2.2	1.8	.9	.5	.7	1.4	1.6	.6
Rye, spring	103–108	2.0	2.8	2.8	2.0	2.4	2.8	2.6	3.3	3.6	3.3	3.3	2.4	3.0	2.7	3.5	2.8	2.0	.8	1.3	2.3	2.9	1.1
Cowpea	169–174	1.4	1.8	2.3	2.1	2.5	3.2	2.7	3.3	3.7	3.5	3.5	2.3	3.5	2.7	3.8	2.7	1.9	.9	1.3	2.5	3.1	1.5
Lupine	175–180	1.1	1.5	1.4	1.3	1.4	1.6	1.4	1.6	2.1	1.8	1.9	1.3	1.9	1.6	2.0	1.6	1.2	.7	1.0	1.6	2.0	.9
Millet, Kursk	181–186	1.2	1.8	2.0	1.7	1.9	2.3	1.9	2.5	3.0	2.6	2.7	1.8	2.7	2.1	2.8	1.8	1.1	.5	.9	1.8	2.2	.7
Millet, Siberian	187–192	1.4	1.9	2.0	1.9	2.0	2.1	2.0	2.6	3.1	2.8	3.1	1.9	2.9	2.3	3.0	2.0	1.3	.8	1.1	2.1	2.7	.8
Corn, Northwestern Dent	217–222	1.4	1.9	2.1	1.8	2.2	2.5	2.3	3.1	3.7	3.1	3.1	2.0	2.9	2.2	3.2	1.9	1.3	.6	1.1	2.1	2.6	.8
Corn, Algeria	238–242	.8	1.2	1.3	1.5	1.7	2.3	1.9	2.7	3.3	2.9	3.1	1.9	3.2	2.4	3.2	2.3	1.8	.6	1.4	2.7	3.3	1.0
Sorghum, Minnesota Amber	205–210	.8	1.4	1.5	1.4	1.8	2.1	2.1	2.9	3.4	2.9	3.0	1.9	3.0	2.4	3.1	2.1	1.9	.6	1.3	2.3	2.9	1.0
Sorghum, Dakota Amber	211–216	1.0	1.5	1.6	1.5	1.8	2.2	1.9	2.5	3.4	2.7	3.0	1.7	2.9	2.2	3.3	2.2	1.8	.9	1.1	2.6	2.9	1.1

TABLE I.—*Measurements of environmental factors and daily transpiration, June 11 to September 15, 1914*—Continued

JULY 1 TO 22—continued

Item.	Pot No	July.																					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Daily transpiration, kgm.—Continued.																							
Sudan grass	410–414	.6	1.0	1.2	1.3	1.6	2.0	1.9	2.7	3.5	3.2	3.3	2.1	3.3	2.6	3.8	2.6	2.4	.8	1.4	2.8	3.7	1.1
Sudan grass (in open)	319–323	.4	.4	.7	.5	.9	1.3	1.2	1.8	2.3	2.3	2.6	1.7	2.5	2.3	3.1	2.1	2.0	.5	1.1	2.4	3.0	.9
Amaranthus	163–168	.9	1.1	1.1	1.1	1.5	1.6	1.5	1.6	2.1	1.5	1.6	1.1	1.6	C	.1	0	.....	.2	0	0	.3	.1
Alfalfa, E23–20–52	109–114	1.5	2.0	2.2	1.9	2.3	3.1	2.9	3.7	4.3	3.8	C	.1	.3	.2	.3	.3	.....	.4	.3	.7	1.1	.4
Alfalfa, E23	115–120	1.8	2.5	2.6	2.3	2.8	3.7	3.3	4.5	4.8	4.3	C	.1	.3	.1	.3	.2	.....	.4	.3	.7	1.2	.5
Alfalfa, E23 (in open)	295–300	1.7	1.9	2.3	1.9	2.5	3.1	3.0	4.3	4.6	4.6	C	.1	.2	.3	.4	.3	.0	.2	.3	.9	1.4	.6
Alfalfa, 162–98A	127–132	4.7	6.2	6.9	5.5	6.2	7.3	6.7	8.3	6.8	5.4	C	.3	.6	.6	1.0	1.0	.6	.6	.8	1.7	2.6	1.3

JULY 23 TO AUG. 13.

Item.	Pot No.	July.									August.												
		23	24	25	26	27	28	29	30	31	1	2	3	4	5	6	7	8	9	10	11	12	13
Evaporation (shallow tank) kgm. per sq. meter		8.84	10.33	9.73	6.70	8.35	11.96	12.75	9.97	7.58	12.99	10.79	9.82	11.89	10.76	14.49	12.90	13.27	11.59	14.34	10.00	12.90	10.79
Evaporation (deep tank), mm		5.34	6.46	6.46	4.75	5.01	7.80	8.76	4.90	5.44	9.07	7.14	7.14	8.30	6.43	10.42	8.26	8.26	8.44	8.76	6.71	8.10	8.10
Evaporation (deep tank), inches		.210	.254	.254	.187	.197	.307	.345	.193	.214	.357	.281	.281	.327	.253	.410	.325	.325	.332	.345	.264	.319	.319
Air temperature, max., °C		31.1	32.2	32.2	33.3	35.6	33.9	35.0	31.1	31.1	33.3	29.4	29.4	33.9	33.3	35.0	35.0	35.0	27.8	27.2	27.8	34.4	32.2
Air temperature, min., °C		14.4	12.8	14.4	15.6	14.4	13.9	17.2	16.1	16.1	17.8	12.8	15.0	13.9	17.2	18.3	15.6	18.3	10.6	11.1	13.9	13.9	15.0
Air temperature, integrated, mean, °C		22.2	23.3	22.8	22.2	22.8	22.8	25.6	22.2	21.1	24.4	20.6	22.2	23.9	25.0	26.1	25.6	26.1	20.0	20.0	20.0	23.9	21.7
Air temperature, max., °F		88	90	90	92	96	93	95	88	80	92	85	85	93	92	95	95	95	82	81	82	94	90
Air temperature, min., °F		58	55	58	69	58	57	63	61	61	64	55	59	57	63	65	60	65	51	52	57	57	59

Air temperature, integrated, mean, °F.	.....	72	74	73	72	73	73	78	72	70	76	69	72	75	77	79	78	79	68	68	68	75	71
Integrated radiation, cal. per sq. cm.	.....	907	803	711	731	696	848	874	840	774	909	867	867	833	806	872	813	808	702	838	961	827	828
Integrated wet-bulb depression, deg. hrs.	.....	136	189	141	124	164	170	211	108	79	186	151	161	199	228	269	244	275	202	203	168	250	159
Wind velocity, miles per hour	.....	3.4	3.8	4.0	3.5	2.8	4.5	7.4	6.0	4.8	7.8	4.3	4.3	6.4	6.4	11.1	5.8	5.9	6.6	12.5	6.0	7.0	8.3
Wind velocity, meters per second	.....	1.5	1.7	1.8	1.6	1.3	2.0	3.3	2.7	2.1	3.5	1.9	1.9	2.9	2.9	5.0	2.6	2.6	2.9	5.6	2.7	3.1	3.7
Daily transpiration, kgm.:																							
Wheat, Kubanka	1–6	2.6	2.7	2.1	1.7	2.0	2.3	2.2	1.2	.9	1.5	.9	.8	.8	.7	.....	.....	.....	.....	.....	.....	.....	.....
Wheat, Galgalos	7–12	2.9	3.4	2.8	2.1	2.6	3.1	3.7	1.7	1.3	2.4	1.5	1.4	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Oat, Swedish Select	91–96	2.5	3.0	2.0	1.7	1.8	2.4	2.0	1.0	1.0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Oat, Burt	97–102	1.7	2.1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Barley, Hannchen	85–90	.9	1.0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Rye, spring	103–108	1.9	2.1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Cowpea	169–174	1.9	2.4	2.2	1.6	1.8	2.3	2.3	.9	1.0	1.5	1.0	1.0	1.1	1.1	1.2	1.2	1.2	.9	.9	.8	.....	.....
Lupine	175–180	1.4	1.6	1.2	1.3	1.3	1.8	2.0	1.2	1.2	1.8	1.4	1.3	1.4	1.5	1.5	1.4	1.2	1.0	.9	.8	.....	.....
Millet, Kursk	181–186	1.5	1.9	1.4	1.2	1.5	1.8	2.1	.5	1.1	1.9	1.3	1.4	1.7	1.6	1.7	1.8	1.8	1.3	1.4	1.2	.....	.....
Millet, Siberian	187–192	1.7	2.2	1.6	1.5	1.7	2.2	2.3	.6	1.2	2.0	1.4	1.5	1.9	1.8	2.0	2.1	1.9	1.3	1.4	1.2	.....	.....
Corn, Northwestern Dent	217–222	1.7	2.2	1.8	1.4	1.8	2.0	2.6	.7	1.2	2.0	1.3	1.5	1.8	1.5	1.8	1.8	1.8	1.0	1.1	.8	1.5	1.1
Corn, Algeria	238–242	2.4	2.6	2.4	2.0	2.1	3.3	3.5	1.8	1.5	3.2	2.4	2.7	2.9	2.8	3.7	3.1	3.3	2.0	2.2	1.9	3.0	2.1
Sorghum, Minnesota Amber	205–210	1.9	2.6	2.1	1.9	2.0	2.7	3.3	1.9	1.4	2.6	1.9	2.0	2.6	2.4	3.2	2.7	2.9	1.8	2.2	1.7	2.3	1.8
Sorghum, Dakota Amber	211–216	1.9	2.5	2.2	1.8	2.0	2.7	3.2	1.7	1.3	2.4	1.8	2.0	2.4	2.2	2.9	2.6	2.7	1.6	1.9	1.5	2.4	1.5
Sudan grass	410–414	2.3	3.0	2.1	2.0	2.2	3.2	3.6	2.1	1.6	3.1	2.1	2.4	3.1	2.9	3.6	3.4	3.6	1.8	2.3	1.6	cc .2	
Sudan grass (in open)	319–323	2.1	2.7	2.1	2.1	2.1	3.2	3.7	2.0	1.2	3.0	1.8	2.1	2.7	2.7	3.2	3.3	3.4	1.8	1.8	1.6	cc .3	
Amaranthus	163–168	.1	.3	.2	.3	.4	.6	.9	.3	.6	.9	.8	.8	.9	.9	1.0	1.0	1.1	1.0	1.0	.9	1.2	C
Alfalfa, E23–20–52	109–114	.9	1.3	1.2	1.0	1.2	1.9	2.2	1.3	1.3	2.3	2.1	2.3	2.6	2.8	3.3	3.3	3.2	2.8	3.2	2.7	3.9	3.0
Alfalfa, E23	115–120	1.0	1.4	1.3	1.1	1.4	2.1	2.5	1.6	1.5	2.6	2.3	2.6	3.1	3.1	3.8	3.9	3.9	3.3	3.9	3.3	4.7	3.5
Alfalfa, E23 (in open)	295–300	1.2	1.7	1.6	1.4	1.7	2.5	2.9	2.0	1.4	3.1	2.5	2.6	3.0	3.2	3.6	4.0	4.1	3.4	3.3	2.9	4.3	3.2
Alfalfa, 162–98A	127–132	2.1	3.0	2.6	2.4	2.7	4.2	4.8	3.4	2.8	4.8	4.4	4.7	5.8	5.5	6.6	5.7	5.6	3.9	5.5	5.2	7.5	4.6

TABLE I.—*Measurements of environmental factors and daily transpiration, June 11 to September 25, 1914*—Continued

AUG. 14 TO SEPT. 4

Item.	Pot No.	August.																		September.			
		14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3	4
Evaporaton (shallow tank), kgm. per sq. meter		11.83	15.76	14.86	12.38	11.13	9.33	8.78	9.30	7.89	10.22	12.78	5.38	7.74	6.64	8.69	8.38	8.20	10.57	9.30	9.76	10.12	11.22
Evaporation (deep tank), mm.		5.92	10.42	8.18	5.28	6.71	5.11	5.48	5.84	6.30	7.12	7.12	5.00	4.60	3.76	5.54	5.29	4.98	4.73	7.60	7.04	5.24	5.94
Evaporation (deep tank), inches		.233	.410	.322	.208	.264	.201	.216	.230	.248	.280	.280	.197	.181	.148	.218	.208	.196	.186	.299	.277	.226	.234
Air temperature, max., °C		34.4	36.7	37.8	38.3	30.6	31.1	33.3	28.9	30.0	28.9	31.7	21.7	27.8	22.2	28.3	28.9	30.6	29.4	28.3	27.8	32.2	33.3
Air temperature, min., °C		16.7	14.4	15.6	15.0	13.9	13.3	13.3	15.0	7.8	11.7	10.6	9.4	7.2	10.0	4.4	7.2	5.6	9.4	4.4	10.6	10.0	13.9
Air temperature, integrated mean °C		24.4	26.7	26.1	24.4	21.1	21.7	21.1	21.1	20.0	20.6	21.1	15.0	17.2	16.1	19.4	18.3	20.0	20.0	14.4	17.8	20.6	22.2
Air temperature, max., °F		94	98	100	101	87	88	92	84	86	84	89	71	82	72	83	84	87	85	83	82	90	92
Air temperature, min., °F		62	58	60	59	57	56	56	59	46	53	51	49	45	50	40	45	42	49	40	51	50	57
Air temperature, integrated mean, °F		76	80	79	76	70	71	70	70	68	69	70	59	63	61	67	65	68	68	58	64	69	72
Integrated radiation, cal. per sq. cm		889	810	900	699	682	795	657	674	502	843	837	556	435	615	731	783	680	810	727	743	810	606
Integrated wet-bulb depression, deg. hr		244	319	326	237	143	114	100	110	151	153	193	50	60	56	133	137	141	178	100	161	177	219
Wind velocity, miles per hr		6.0	7.1	5.1	5.9	7.1	6.9	4.2	7.3	5.9	6.8	8.5	9.0	8.1	4.3	4.3	4.4	4.4	4.8	7.8	7.3	4.4	4.8
Wind velocity, meters per sec		2.7	3.2	2.3	2.6	3.2	3.1	1.9	3.3	2.6	3.0	3.8	4.0	3.6	1.9	1.9	2.0	2.0	2.1	3.5	3.3	2.0	2.1
Daily transpiration, kgms:																							
Corn, Northwestern Dent	217–222	1.3	1.7	1.5	1.3	.1	.6	1.0	.5	.6	.6	.5	0	0	.6	.3	.4	.3	.....	.....	.....	.....	.....
Corn, Algeria	238–242	2.0	3.1	3.2	2.4	1.1	1.3	1.7	1.1	1.3	1.3	1.2	0	.2	.9	.9	1.1	.9	.....	.....	.....	.....	.....
Sorghum, Minnesota Amber	205–210	2.1	2.9	2.9	2.4	1.1	1.3	1.6	.9	1.3	1.4	1.6	.4	.2	.7	1.3	1.1	1.1	1.3	.....	.....	.....	.....
Sorghum, Dakota Amber	211–216	2.1	2.8	2.7	2.3	.9	1.3	1.4	.8	1.2	1.2	1.5	.3	0	.8	1.1	1.1	1.0	1.1	.....	.....	.....	.....
Sudan grass	410–414	.2	.4	.3	.5	.....	.4	.8	.5	.5	.6	.8	.1	.....	.7	.6	.7	.6	.8	.3	.6	.7	.8
Sudan grass (in open)	319–323	.2	.3	.4	.4	0	.5	.6	.4	.6	.7	.9	.3	.1	.5	.7	.7	.7	1.0	.6	.7	.9	1.0
Amaranthus	163–168	0	.2	0	0	.....	.1	.4	0	.2	.2	.1	.....	.....	.4	.2	.4	.2	.3	.1	.3	.4	.4
Alfalfa, E23–20–52	109–114	2.7	C	.2	.3	.....	.3	.6	.4	.7	.9	1.2	.3	.5	.8	1.1	1.5	1.4	1.7	1.5	1.9	2.0	2.2
Alfalfa, E23	115–120	3.1	C	.1	.3	.....	.2	.6	.3	.6	.8	1.1	.3	.5	.8	1.2	1.5	1.5	2.0	1.7	2.1	2.3	2.5
Alfalfa, E23 (in open)	295–300	C	.2	.2	.3	0	.3	.5	.5	.8	1.1	1.2	.4	.5	.8	1.3	1.6	1.6	2.1	1.7	2.0	2.4	2.6
Alfalfa, 162–98A	127–132	2.9	C	.2	.3	.....	.3	.8	.5	.9	1.3	1.7	.6	.8	1.1	1.7	2.2	2.1	2.7	2.4	2.6	2.8	2.5

SEPT. 5 TO 25

Item.	Pot No.	September.																				
		5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Evaporation (shallow tank), kgm. per sq. cm		12.08	7.58	8.62	7.37	7.65	10.15	9.67	13.12	5.63	9.85	14.98	7.74	7.89	12.14	10.76	13.82	10.15	6.06	9.36	8.50	12.48
Evaporation (deep tank), mm		6.96	5.46	4.65	5.21	4.96	7.24	7.09	11.50	4.12	5.54	9.42	4.04	4.35	7.52	8.16	7.88	6.96	4.40	4.65	5.52	8.14
Evaporation (deep tank), inches		.274	.215	.183	.205	.195	.285	.279	.453	.162	.218	.371	.159	.171	.296	.321	.310	.274	.173	.183	.217	.320
Air temperature, max., °C		32.2	26.7	29.4	27.8	27.8	28.3	32.8	32.8	17.8	21.1	33.3	26.1	31.1	32.2	31.1	31.1	20.0	20.0	21.7	26.7	28.9
Air temperature, min., °C		10.0	11.1	8.9	13.9	10.0	9.4	13.3	5.0	−.6	1.7	6.7	6.1	12.8	15.6	12.2	12.8	−.6	2.8	3.9	8.3	8.3
Air temperature, integrated mean, °C		21.1	19.4	20.0	19.4	18.3	18.3	21.7	18.3	7.8	17.8	21.7	15.0	21.1	22.8	20.6	21.1	10.0	13.9	12.2	16.7	18.3
Air temperature, max., °F		90	80	85	82	82	83	91	91	64	70	92	79	88	90	88	88	68	68	71	80	84
Air temperature, min., °F		50	52	48	57	50	49	56	41	31	35	44	43	55	60	54	55	31	37	39	47	47
Air temperature, integrated mean, °F		70	67	68	67	65	65	71	65	46	64	71	59	70	73	69	70	50	57	54	62	65
Integrated radiation, cal. per sq. cm		714	573	642	573	564	813	753	707	492	823	753	731	630	808	776	738	692	722	842	820	750
Integrated wet-bulb depression, deg. hr		226	117	81	56	74	178	173	213	86	122	262	146	140	208	169	196	124	126	123	194	223
Wind velocity, {miles per hr		6.3	8.0	7.8	7.5	5.2	5.7	9.7	11.4	5.2	7.3	12.1	4.8	4.3	9.4	9.9	10.8	9.2	3.3	4.0	4.7	9.3
Wind velocity, {meters per sec		2.8	3.6	3.5	3.4	2.3	2.5	4.3	5.1	2.3	3.3	5.4	2.1	1.9	4.2	4.4	4.8	4.1	1.5	1.8	2.1	4.2
Daily transpiration, kgm.:																						
Sudan grass	410–414	.9	.5	.6	.4	.5	.7	1.0	.9	.2	.2	1.1	.3	.6	.9	.9	1.0	.4	.2	.5	.5	.9
Sudan grass (in open)	319–323	1.0	.6	.7	.6	.6	.9	1.2	1.4	.2	.3	1.1	.4	.9	1.1	1.2	1.0	.6	.2	.2	.8	.9
Amaranthus	163–168	.4	.3	.3	.1	.2	.4	.5	.4	.2	.2	.6	.2	.4	.4	.4	.5	.2	.0	.2	.2	.5
Alfalfa, E23–20–52	109–114	2.5	2.1	2.0	1.7	1.9	2.5	2.9	3.3	1.5	1.8	3.2	2.1	2.7	3.7	3.4	3.6	2.6	2.0	2.4	2.7	3.5
Alfalfa, E23	115–120	2.9	2.3	2.4	2.0	2.4	3.0	3.3	3.9	1.8	2.3	3.9	2.6	3.2	4.6	4.3	4.4	3.1	2.4	2.7	3.2	4.1
Alfalfa, E23 (in open)	295–300	3.0	2.4	2.4	2.2	2.6	3.1	3.4	3.9	1.6	2.2	3.8	3.0	3.2	4.8	4.8	4.5	3.1	2.3	2.9	3.4	4.2
Alfalfa, 162–98A	127–132	3.7	3.0	2.6	2.7	3.1	3.4	4.2	4.9	2.3	2.6	4.5	3.7	4.0	5.7	5.3	5.4	3.7	3.1	3.5	3.2	4.6

55858°—16—2

The evaporation from the shallow tank as given in Table I is expressed in kilograms per square meter of water surface per day, calculated from the observed evaporation from a shallow blackened tank 6,540 sq. cm. in area and 2.5 cm. in depth, the depth of water being maintained automatically at about 1 cm. The evaporation from the deep tank (8 feet, or 243 cm., in diameter; depth of water, 50 cm.) is expressed in terms of the thickness of the layer of water evaporated each day, given both in inches and in millimeters. Since the loss of 1 kgm. of water from an area of 1 square meter represents a sheet of water 1 mm. in thickness, the daily evaporation from the two tanks is easily compared.

The maximum, minimum, and mean temperature of each day is given in Table I in both Fahrenheit and centigrade units. The mean daily temperature was determined by integrating the area bounded by the thermograph record with the aid of a planimeter, which gives a better representation of the mean temperature than the mean of the maximum and minimum values.

The daily radiation represents the total number of small calories received during the day on a surface 1 sq. cm. in area kept normal to the sun's rays. The radiation values given in Table I were computed from the records of a differential thermograph calibrated by means of a standardized Abbot silver-disk pyrheliometer.

The wet-bulb depression is expressed in hour degrees on both temperature scales and represents the summation of the depression for each hour of the day beginning at 5 a. m.

The mean wind velocity for the day as measured by a Robinson anemometer 3 feet above the ground is given in miles per hour and meters per second.

The daily values of the weather factors and the daily transpiration during the growing season of 1914 as given in Table I are plotted in figure 2. The graphs of the two evaporation tanks are seen to be similar though not identical. This similarity is of special interest when the difference in the hourly distribution of the evaporation from the two tanks is considered. The loss from the small shallow tank is confined almost wholly to the daylight hours, while the large deep tank shows a marked evaporation at night, due to the heat stored during the day in the large volume of water. The writers will show later that the daily transpiration is more closely correlated with the daily evaporation from the shallow tank than with that from the deep tank.

The daily transpiration is, of course, dependent not only upon the environment but upon the relative water requirement of the various species, the size of the plants, and the stage of growth. The daily transpiration is therefore supplemented in Table II with a statement of the period of growth, yield of dry matter, and water requirement of each variety. To this table has also been added the variety of plant used, the botanical name, and the pot numbers.

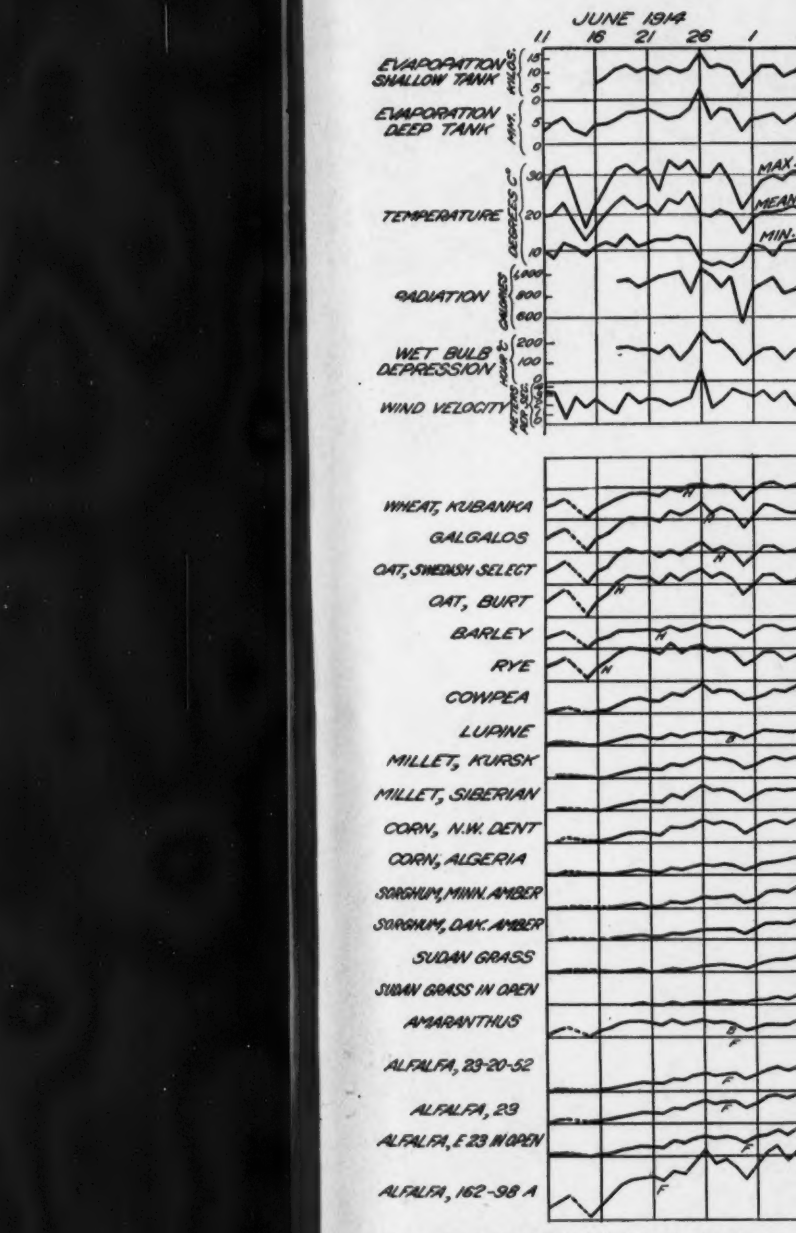
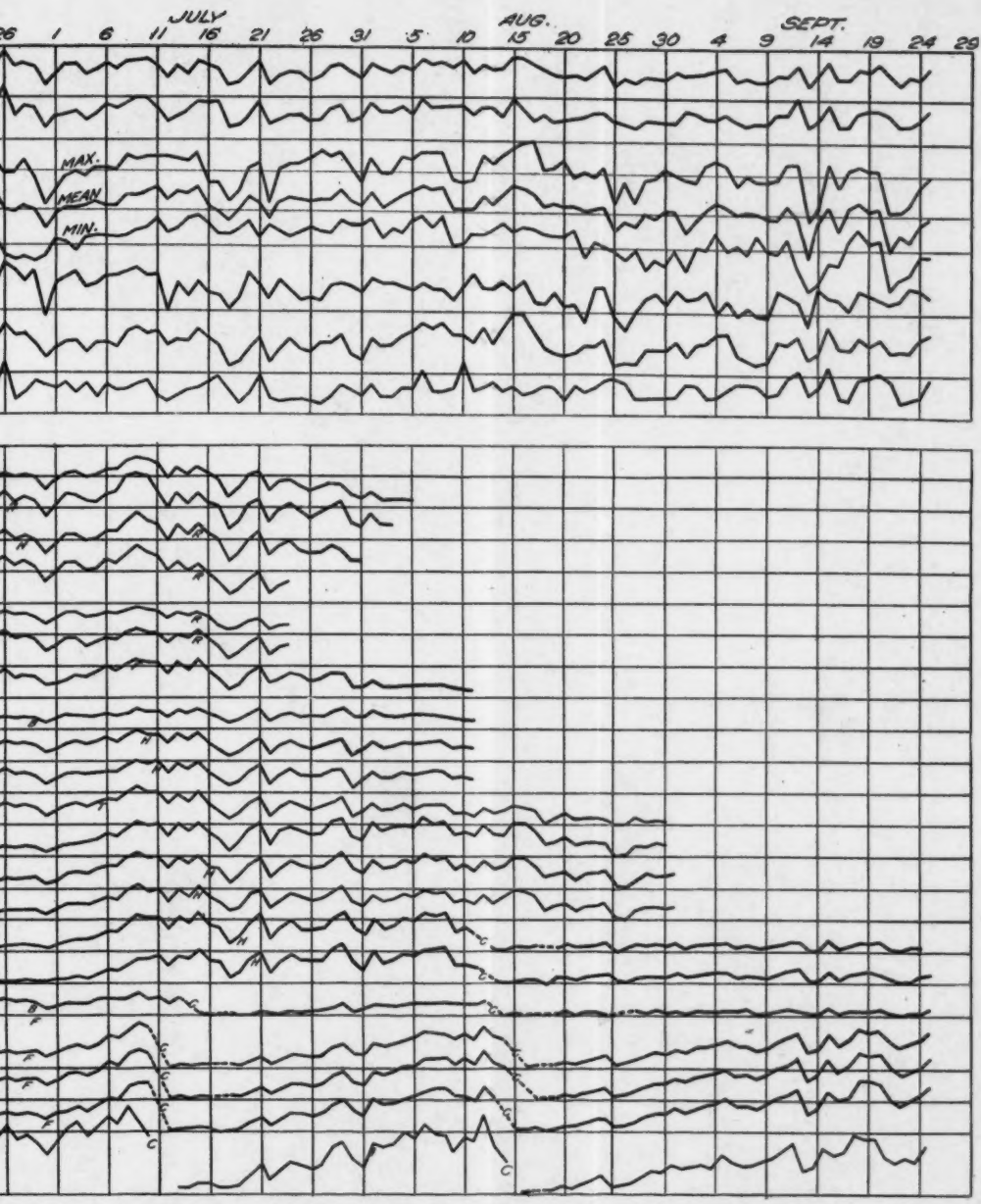


FIG. 2.—Graphs showing the daily intensity of environmen
per square meter. The evaporation from the large tank is
on a surface normal to the sun's rays; the wet-bulb depressi
(zero) lines for each crop representing 3 kgm., except for al
the graph indicates that the crop was cut and was followe
ripening.



of environmental factors and the daily transpiration of 22 crops for the year 1914. The evaporation from the small tank is expressed in kilograms e large tank is given in millimeters. The temperatures are expressed in °C.; the total radiation for the day in small calories per square centimeter t-bulb depression in hour degrees C.; the wind velocity in meters per second. The transpiration is given in kilograms, the space between the base ., except for alfalfas E23–20–52 and 162–98A, the base lines of which are 5 and 6 kgm., respectively, below that of the crop above. The letter *C* in d was followed by a new growth from the established root system. *H* signifies that plants were heading; *F*, flowering; *T*, tasseling; and *R*,

TABLE II.—*Period of growth, yield, and water requirement of plants used in 1914 transpiration measurements*

Crop.	Variety.	Botanical name.	Period of growth.	Pot no.	Mean dry matter.	Mean water.	Mean grain.	Water requirement based on dry matter.
					Gm.	*Kgm.*	*Per cent.*	
Wheat	Kubanka (C. I. 1440)	*Triticum durum*	May 9–Aug. 6	1–6	306	160	38	518±6
Do	Galgalos (C. I. 2398)	*Triticum aestivum*	May 9–Aug. 11	7–12	298	186	33	624±5
Oat	Swedish Select (C. I. 134)	*Avena sativa*	May 9–Aug. 1	91–96	264	158	42	599±2
Do	Burt (C. I. 293)	do	May 9–July 25	97–102	251	154	42	615±6
Barley	Hannchen (C. I. 531)	*Hordeum distichon*	do	85–90	182	91	43	501±5
Rye	Spring (C. I. 73)	*Secale cereale*	do	103–108	195	121	27	622±7
Cowpea	S. P. I. 29282	*Vigna sinensis*	May 28–Aug. 12	169–174	170	112	34	659±5
Lupine	White (S. P. I. 35477)	*Lupinus albus*	do	175–180	90	76	18	870±34
Millet	Kursk (S. P. I. 34771)	*Chaetochloa italica*	June 9–Aug. 12	181–186	301	89	28	295±2
Do	Siberian (A. D. I. 3–4)	do	do	187–192	318	100	28	316±5
Corn	Northwestern Dent	*Zea mays*	June 3–Aug. 31	217–222	304	112	.....	368±6
Do	Algeria	do	do	238–242	417	137	.....	331±4
Sorghum	Minnesota Amber (A. D. I. 341–13)	*Andropogon sorghum*	June 9–Sept. 1	205–210	457	130	32	284±3
Do	Dakota Amber (A. D. I. 341–10–4)	do	do	211–216	427	126	34	296±1
Sudan grass:								
In screened inclosure—								
First crop	S. P. I. 25017	*Andropogon sorghum aethiopicus.*	June 10–Aug. 12	410–414	301	110	.....	366±3
Second crop			Aug. 13–Oct. 15	410–414	59	32	.....	540±6
Combined			June 10–Oct. 15	410–414	360	142	.....	394±4
In open—								
First crop			June 10–Aug. 12	319–323	216	88	.....	405±12
Second crop			Aug. 13–Oct. 14	319–323	61	38	.....	626±16
Combined			June 10–Oct. 14	319–323	277	126	.....	455±9
Amaranthus:								
First crop		*Amarantkus retroflexus*	June 3–July 14	163–168	124	39	.....	313±4
Second crop			July 15–Aug. 13	163–168	54	16	.....	304±3
Third crop			Aug. 14–Oct. 17	163–168	42	12	.....	287±4
Combined			June 3–Oct. 17	163–168	220	67	.....	306±1
Alfalfa:								
First crop	Grimm (A. D. I. E–23–20–52)	*Medicago sativa*	June 5–July 11	109–114	72	45	.....	619±5
Second crop			July 12–Aug. 15	109–114	66	60	.....	900±21
Third crop			Aug. 16–Oct. 26	109–114	120	130	.....	1,088±20
Combined			June 5–Oct. 26	109–114	258	234	.....	906±11

TABLE II.—*Period of growth, yield, and water requirement of plants used in 1914 transpiration measurements*—Continued

Crop.	Variety.	Botanical name.	Period of growth.	Pot no.	Mean dry matter.	Mean water.	Mean grain.	Water requirement based on dry matter.
					Gm.	*Kgm.*	*Per cent.*	
Alfalfa:								
In screened inclosure—								
First crop	Grimm (A. D. I. E-23)	*Medicago sativa*	June 5–July 11	115–120	87	53		610±3
Second crop			July 12–Aug. 15	115–120	77	70		906±14
Third crop			Aug. 16–Oct. 26	115–120	142	149		1,055±12
Combined			June 5–Oct. 26	115–120	306	272		890±6
In open—								
First crop			June 5–July 11	295–300	67	51		767±13
Second crop			July 12–Aug. 14	295–300	58	67		1,159±29
Third crop			Aug. 15–Oct. 27	295–300	142	159		1,124±24
Combined			June 5–Oct. 27	295–300	267	276		1,039±19
Alfalfa:								
First crop	Grimm (A. D. I. 162-98-A)	do	May 9–July 11	128–132	203	146		720±5
Second crop			July 12–Aug. 15	128–132	146	118		809±14
Third crop			Aug. 16–Oct. 26	128–132	209	187		899±3
Combined			May 9–Oct. 26	128–132	557	452		811±5

While large daily fluctuations occur in all the physical factors, the graphs do not show a marked "run" as the season advances. In other words, the seasonal change is not large. The evaporation shows a slight maximum in early August. The radiation is at its maximum in the latter part of June, at which time the sun reaches its greatest altitude. From this time onward the maximum intensity of the radiation (representing cloudless days) gradually decreases. The wind velocity, on the other hand, tends to increase slowly as the season advances. The maximum temperature and maximum wet-bulb depression occur during the middle of August.

MEASUREMENTS IN 1915

The daily transpiration measurements in 1915 were begun as soon as the crops were established and include, therefore, the whole growth period (Table III). The season was exceptionally rainy, which was unfortunate from the standpoint of the transpiration measurements, as the plants were often so wet in the morning that it was impossible to determine the transpiration of the preceding day. In such cases the mean transpiration has been given for the two or three days included in the rainy period. Such breaks in the daily record are indicated by dotted lines in figure 3, in which the data in Table III are presented graphically. Supplementary data relative to the plants used in the 1915 measurements are given in Table IV.

TABLE III.—*Measurements of environmental factors and daily transpiration, May 22 to September 20, 1915*

MAY 22 TO JUNE 20

Item.	Pot No.	May.						June.												
		22–23	24	25	26–27	28	29–31	1	2–4	5–6	7	8–9	10–11	12	13	14	15	16	17	18	19–20
Evaporation (deep tank) ..... mm		3.40	2.95	5.62	5.92	2.79	2.57	0.56	3.56	8.43	3.71	4.09	6.53	8.66	3.10	4.57	4.04	6.20	5.46	5.82	3.91
Evaporation (deep tank) ..... inches		.134	.116	.221	.233	.110	.101	.022	.140	.332	.146	.161	.257	.341	.122	.180	.159	.124	.215	.229	.154
Air temperature, max. °C		22.2	25.0	24.4	14.4	18.3	16.7	21.7	18.3	13.9	20.0	23.9	23.3	21.7	15.6	21.1	25.6	23.3	25.6	27.8	22.2
Air temperature, min. °C		7.8	11.1	9.4	6.7	2.8	8.3	10.0	6.7	3.9	7.2	10.6	11.7	3.3	6.1	7.8	8.3	15.0	9.4	11.1	12.2
Air temperature, integrated mean. °C		15.0	19.4	16.7	10.0	11.1	11.7	16.1	12.8	8.3	13.3	16.7	17.8	12.2	10.0	14.4	17.2	18.3	17.8	18.3	16.1
Air temperature, max. °F		72	77	76	58	65	62	71	65	57	68	75	74	71	60	70	78	74	78	82	72
Air temperature, min. °F		46	52	49	44	37	47	50	44	39	45	51	53	38	43	46	47	59	49	62	54
Air temperature, integrated mean. °F		59	67	62	50	52	53	61	55	47	56	62	64	54	50	58	63	65	64	65	61
Wind velocity ..... miles per hr		5.2	5.0	10.1	16.6	7.4	4.8	7.3	4.4	7.5	7.4	7.0	10.6	11.0	4.3	5.3	4.9	10.8	7.0	8.6	5.7
Wind velocity ..... meters per sec.		2.3	2.2	4.5	7.4	3.3	2.1	3.3	2.0	3.4	3.3	3.1	4.7	4.9	1.9	2.4	2.2	4.8	3.1	3.8	2.5
Daily transpiration, kgm.:																					
Wheat, Kubanka	1–6	.1	.2	.1	.....	.1	.1	.1	.1	.....	.5	.4	.6	.7	.4	.7	1.0	1.1	1.1	1.0	.8
Wheat, Galgalos	7–12	.1	.2	.1	.....	.1	.1	.2	.2	.....	.5	.5	.7	.7	.2	.9	1.0	1.0	1.1	1.1	.8
Wheat, Washington Bluestem	13–18	.0	.1	.1	.....	.1	.0	.1	.1	.....	.3	.3	.5	.6	.3	.6	1.0	1.0	.9	1.2	.9
Wheat, Turkestan	19–24	.0	.0	.1	.....	.0	.0	.1	.1	.....	.3	.4	.7	.7	.3	.8	1.3	1.2	1.1	1.6	1.0
Wheat, Marquis	103–108	.0	.0	.2	.....	.1	.0	.1	.2	.....	.4	.5	.7	.6	.2	.9	1.1	1.1	.9	1.2	.8
Wheat, Kubanka	109–114	.....	.1	.2	.....	.1	.0	.0	.2	.....	.3	.4	.7	.6	.3	.8	1.0	1.1	.9	1.2	.9
Wheat, Preston	127–132	.....	.....	.....	.....	.0	.....	.2	.1	.....	.2	.4	.6	.4	.3	1.2	1.0	1.1	1.3	1.1	1.1
Oat, Swedish Select	139–144	.....	.....	.....	.....	.0	.0	.1	.1	.....	.2	.3	.5	.3	.2	1.0	.8	1.0	1.1	1.2	1.0
Oat, Burt	145–150	.....	.....	.....	.....	.0	.0	.1	.....	.....	.1	.2	.3	.2	.5	.6	.8	.8	1.0	.9	.9
Barley, Hannchen	133–138	.....	.....	.....	.....	.0	.0	.1	.1	.....	.2	.3	.5	.2	.2	1.2	.9	.9	1.1	1.1	1.0
Rye, spring	151–156	.....	.....	.....	.....	.0	.0	.1	.....	.....	.2	.3	.5	.4	.7	.8	1.1	1.0	1.2	1.1	1.1
Flax, North Dakota (C. I. 13)	157–162	.....	.....	.....	.....	.....	.....	.0	.....	.....	.0	.0	.2	.....	.4	.1	.4	.3	.5	.2	.5
Flax, North Dakota (C. I. 19)	187–192	.....	.....	.....	.....	.....	.....	.0	.....	.....	.0	.0	.2	.....	.3	.3	.4	.3	.5	.3	.5
Flax, Smyrna	163–168	.....	.....	.....	.....	.....	.....	.0	.....	.....	.0	.0	.2	.....	.4	.2	.4	.3	.5	.3	.4
Cowpea	217–222	.....	.....	.....	.....	.....	.....	.....	.....	.....	.0	.....	.1	.1	.1	.....	.1	.....	.0	.2	.....
Alfalfa, E–23	193–198	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.0	.2	.0
Alfalfa, 162–98A1	199–204	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.2	.....

JUNE 21 TO JULY 11

Item.	Pot No.	June.									July.										
		21–22	23	24	25	26	27	28	29	30	1	2	3	4	5	6	7	8	9	10	11
Evaporation (shallow tank), kgm. per sq. meter											7.10	2.77	5.80	6.26	6.98	6.28	6.39	4.82	9.19	8.08	8.21
Evaporation (deep tank) mm		5.87	5.64	0.86	5.77	5.03	6.56	3.25	6.20	5.74	8.13	3.46	5.46	3.76	3.15	8.86	4.60	4.22	6.43	6.48	5.82
Evaporation (deep tank) inches		.231	.222	.034	.227	.198	.258	.128	.244	.226	.320	.136	.215	.148	.124	.349	.181	.166	.253	.255	.229
Air temperature, max. °C.		21.7	21.7	23.3	27.2	27.8	27.2	21.7	27.2	22.2	26.7	16.7	23.9	21.1	29.4	32.8	25.0	28.9	30.6	26.7	35.0
Air temperature, min. °C.		11.7	11.7	11.7	8.3	10.6	11.1	12.8	11.7	11.1	8.9	9.4	4.4	7.2	13.3	10.0	14.4	11.7	12.2	16.1	14.4
Air temperature, integrated mean. °C.		16.7	17.2	17.2	18.3	18.9	18.3	16.7	17.8	16.7	17.2	13.3	12.2	13.9	20.6	18.9	19.4	18.3	21.7	21.1	25.0
Air temperature, max. °F.		71	71	74	81	82	81	71	81	72	80	62	75	70	85	91	77	84	87	80	95
Air temperature, min. °F.		53	53	53	47	51	52	55	53	52	48	49	40	45	56	50	58	53	54	61	58
Air temperature, integrated mean. °F.		62	63	63	65	66	65	62	64	62	63	56	54	57	69	66	67	65	71	70	77
Integrated radiation, cal. per sq. cm.										1,015	805	667	764	1,132	963	751	1,013	616	984	904	981
Integrated wet-bulb depression, hr. deg. C.									27	45			84	104	111	132	94	66	115	127	142
Wind velocity miles per hr		8.7	5.1	5.4	8.0	3.8	7.0	5.7	3.5	5.4	8.3	3.5	8.0	2.9	3.7	6.9	5.7	5.2	8.0	6.8	5.5
Wind velocity meters per second		3.9	2.3	2.4	3.6	1.7	3.1	2.5	1.6	2.4	3.7	1.6	3.6	1.3	1.7	3.1	2.5	2.3	3.6	3.0	2.5
Daily transpirations, kgm.:																					
Wheat, Kubanka	1–6	.9	.8	1.2	1.4	1.5	1.5	1.0	1.2	1.8	1.7	.9	1.0	1.2	1.7	1.9	1.7	1.8	1.9	2.1	2.4
Wheat, Galgalos	7–12	.9	.8	1.1	1.4	1.6	1.6	.8	1.3	1.7	1.8	.8	1.1	1.1	1.4	1.8	1.6	1.6	2.2	2.2	2.7
Wheat, Washington Bluestem	13–18	.9	.8	1.1	1.5	1.5	1.7	.8	1.4	1.7	1.6	.8	1.2	1.1	1.5	1.9	1.6	1.6	2.3	2.5	2.8
Wheat, Turkestan	19–24	1.1	1.0	1.3	1.9	2.1	2.3	1.3	1.8	2.5	2.6	1.1	1.8	1.8	2.4	2.4	2.3	2.2	3.1	3.0	3.1
Wheat, Marquis	103–108	.9	.8	1.2	1.4	1.5	1.6	.9	1.2	1.7	1.8	.8	1.0	1.2	1.6	1.9	1.7	1.6	2.1	2.1	3.0
Wheat, Kubanka	109–114	.9	1.0	1.1	1.4	1.7	1.8	1.0	1.5	1.9	2.0	.9	1.3	1.6	1.9	2.1	2.0	1.8	2.4	2.5	2.9
Wheat, Preston	127–132	1.1	1.1	1.3	1.5	1.9	2.0	1.1	1.7	2.3	2.3	1.0	1.4	1.7	2.4	2.4	2.0	2.0	2.8	3.0	3.7
Oat, Swedish, Select	139–144	1.2	1.1	1.4	2.2	2.2	2.4	1.3	2.0	2.7	2.8	1.1	1.7	1.9	2.6	2.7	2.4	2.3	3.8	3.5	4.6
Oat, Burt	145–150	1.1	1.1	1.3	1.6	2.2	2.1	1.1	1.6	2.2	2.3	.8	1.5	1.5	2.3	2.4	2.1	2.0	2.9	2.9	3.7
Barley, Hannchen	133–138	1.2	1.2	1.5	1.6	2.5	2.0	1.3	1.7	2.3	2.2	1.1	1.5	1.6	2.3	2.2	2.0	2.1	3.0	3.2	3.8
Rye, spring	151–156	1.0	1.0	1.4	1.6	2.4	2.1	1.2	1.5	2.1	2.2	.9	1.3	1.5	1.9	2.2	1.7	1.6	2.3	2.3	3.1
Flax, North Dakota (C. I. 13)	157–162	.5	.6	.7	.8	1.5	1.3	.8	1.1	1.6	1.4	.6	1.0	1.0	1.9	1.9	1.9	1.7	1.5	2.4	3.6
Flax, North Dakota (C. I. 19)	187–192	.6	.5	.8	1.0	1.7	1.4	.9	1.2	2.0	2.1	.8	1.3	1.5	2.3	2.7	2.3	2.3	3.5	3.2	4.4
Flax, Smyrna	163–168	.5	.6	.6	.9	1.5	1.5	.7	1.1	1.7	1.7	.8	1.2	1.4	2.0	2.5	2.2	1.9	3.3	3.2	4.1
Cowpea	217–222	.0	.2	.2	.....	.4	.3	.....	.1	.5	.1	.....	.2	.2	.3	.4	.3	.7	.3	.8	.9
Millet	223–228	.....	.....	.....	.....	.....	.2	.....	.....	.2	.....	.....	.2	.1	.2	.3	.3	.4	.3	.6	.8
Sorghum	235–240	.....	.....	.....	.....	.....	.2	.....	.....	.2	.1	.....	.2	.0	.2	.2	.1	.3	.0	.2	.2
Corn	241–246	.....	.....	.....	.....	.....	.2	.....	.....	.5	.....	.3	.0	.0	.1	.2	.1	.2	.1	.3	.4
Potato	307–312	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.4	.0	.....	.3	.1	.2	.3	.2	.3	.5
Amaranthus	211–216	.....	.....	.....	.....	.....	.4	.....	.1	.2	.3	.....	.3	.2	.4	.7	.6	.6	.6	.9	1.5
Sudan grass	253–258	.....	.....	.....	.....	.....	.1	.....	.....	.3	.....	.3	.1	.....	.2	.1	.2	.1	.1	.3	.5
Alfalfa, E–23	193–198	.1	.3	.4	.1	.8	.4	.2	.3	.8	.7	.4	.5	.7	1.0	1.4	1.2	1.3	1.6	1.9	2.5
Alfalfa, 162–98A1	199–204	.1	.2	.3	.2	.5	.3	.1	.2	.5	.6	.2	.4	.5	.8	1.1	1.0	1.0	1.4	1.7	2.1

TABLE III.—*Measurements of environmental factors and daily transpiration, May 22 to September 20, 1915*—Continued

JULY 12 TO AUG. 4

Item.	Pot No.	July.																	August.			
		12	13	14	15	16	17–19	20	21	22	23	24	25	26–27	28	29	30	31[1]	1	2	3	4
Evaporation (shallow tank) kgm. per sq. meter	.....	8.51	7.18	8.93	.....	5.95	5.72	2.49	6.54	8.87	7.98	5.90	6.00	3.95	5.88	7.05	5.40	6.80	4.68	5.69	7.70	6.54
Evaporation (deep tank) mm	.....	6.35	7.77	7.22	4.52	8.74	4.98	2.16	4.85	7.09	6.65	4.68	5.69	3.00	4.57	6.35	5.41	5.84	4.39	4.52	5.74	6.07
Evaporation (deep tank) inches	.....	.250	.306	.284	.178	.344	.196	.085	.191	.279	.262	.184	.224	.118	.180	.250	.213	.230	.173	.178	.226	.239
Air temperature, max. °C.	.....	28.9	31.1	32.2	27.8	28.9	25.6	17.2	31.7	30.6	33.3	27.8	25.0	23.9	28.3	29.4	26.1	27.2	26.7	21.7	26.7	28.3
Air temperature, min. °C.	.....	13.3	11.7	16.1	13.3	13.9	12.2	11.1	14.4	12.2	13.9	8.9	14.4	15.0	13.3	10.6	13.3	11.7	10.6	9.4	13.3	11.1
Air temperature, integrated mean °C.	.....	21.7	21.1	23.9	20.6	20.0	17.2	14.4	23.3	21.1	23.9	19.4	18.3	18.3	20.6	18.3	20.0	18.9	15.6	15.6	17.8	19.4
Air temperature, max. °F.	.....	84	88	90	82	84	78	63	89	87	92	82	77	75	83	85	79	81	80	71	80	83
Air temperature, min. °F.	.....	56	53	61	56	57	54	52	58	54	57	48	58	59	56	51	56	53	51	49	56	52
Air temperature, integrated mean °F.	.....	71	70	75	69	68	63	58	74	70	75	67	65	65	69	65	68	66	60	60	64	67
Integrated radiation, cal. per sq. cm	.....	984	806	1,013	764	645	583	417	1,081	852	793	625	906	570	706	729	694	769	622	860	919	724
Integrated wet-bulb depression, hr. deg. C.	.....	106	101	144	105	89	93	52	103	160	162	79	64	39	63	77	61	84	53	77	77	110
Wind velocity miles per hr.	.....	5.0	6.7	6.0	7.5	8.5	6.7	5.6	5.0	6.7	5.6	5.2	8.9	5.4	4.8	4.9	7.3	7.6	5.4	8.0	2.6	4.4
Wind velocity meters per sec.	.....	2.2	3.0	2.7	3.4	3.8	3.0	2.5	2.2	3.0	2.5	2.3	4.0	2.4	2.1	2.2	3.3	3.4	2.4	3.6	1.2	2.0
Daily transpiration, kgm.:																						
Wheat, Kubanka	1–6	2.3	2.0	2.6	2.1	1.6	1.5	.7	2.1	2.3	2.4	1.3	1.6	1.0	1.2	1.8	1.2	1.7	.6	1.0	1.1	1.4
Wheat, Galgalos	7–12	2.5	2.2	2.8	2.2	1.7	1.5	.5	1.9	2.4	2.5	1.1	1.2	.9	1.1	1.6	.9	1.4	.6	.8	.9	1.2
Wheat, Washington Bluestem	13–18	2.8	2.7	3.2	2.6	2.0	1.8	.8	2.3	2.9	3.2	1.7	1.8	1.2	1.6	2.2	1.5	2.1	1.3	1.4	1.6	1.8
Wheat, Turkestan	19–24	3.0	2.9	4.0	3.0	2.4	2.2	.8	2.5	3.4	3.3	1.6	1.8	1.2	1.9	2.0	1.5	2.0	.7	1.0	1.4	1.6
Wheat, Marquis	103–108	2.8	2.3	3.0	2.3	1.7	1.7	.5	2.0	2.6	2.7	1.4	1.6	1.0	1.5	1.9	1.2	1.8	.7	.9	1.3	1.5
Wheat, Kubanka	109–114	2.8	2.4	3.3	2.5	2.0	1.9	.8	2.5	3.0	3.2	1.7	1.9	1.3	1.7	2.2	1.6	2.2	1.1	1.3	1.8	2.2
Wheat, Preston	127–132	3.1	2.7	3.8	3.3	2.2	2.2	.8	2.8	3.4	3.4	2.0	2.2	1.6	2.1	2.4	1.9	2.5	1.3	1.4	2.0	2.4
Oat, Swedish select	139–144	4.5	4.0	5.4	4.4	3.4	3.2	.9	3.1	4.0	3.8	2.0	2.3	1.5	2.3	3.0	2.2	3.3	1.2	2.0	3.1	3.2
Oat, Burt	145–150	3.7	3.1	4.2	3.2	2.5	2.3	.7	2.6	3.5	3.4	1.8	2.0	1.2	1.9	2.2	1.8	2.0	.7	.9	1.5	1.3
Barley, Hannchen	133–138	3.6	3.1	4.3	3.6	2.8	2.4	.9	2.6	3.0	3.1	1.9	1.9	1.2	1.6	2.0	1.6	2.1	.5	.8	1.2	1.5
Rye, spring	151–156	2.3	2.4	3.0	2.4	1.7	1.7	.4	2.0	2.6	2.7	1.3	1.5	1.0	1.5	1.6	1.2	1.6	.8	1.0	1.3	1.5
Flax, North Dakota (C. I. 13)	157–162	3.1	2.6	3.5	2.9	2.0	2.1	.6	2.5	2.9	2.9	1.6	1.7	1.2	1.7	2.0	1.5	2.1	.7	1.2	1.8	1.5
Flax, North Dakota (C. I. 19)	187–192	4.2	3.5	4.7	3.9	2.9	2.8	.9	3.2	3.8	2.8	1.5	2.1	1.2	2.2	2.4	2.2	2.7	1.2	1.6	2.3	2.0
Flax, Smyrna	163–168	3.8	3.3	4.7	3.9	3.0	2.9	1.1	3.4	4.0	3.2	1.8	2.3	1.2	1.5	2.3	2.0	2.4	1.2	1.9	2.4	2.0
Cowpea	217–222	1.1	1.0	1.3	1.3	.9	1.0	.3	1.3	1.5	2.0	.9	1.0	.7	1.2	1.6	.9	1.6	1.0	.8	1.1	1.1
Millet	223–228	.9	.9	1.3	1.1	.8	1.0	.3	1.4	1.5	2.2	.9	1.1	.7	1.2	1.6	.9	1.5	.5	.7	1.4	1.3
Sorghum	235–240	.4	.4	.5	.4	.2	.4	.1	1.0	1.1	1.0	.4	.6	.4	.8	1.1	.5	1.1	.4	.5	1.1	1.0
Corn	241–246	.5	.3	1.0	.5	.3	.6	.1	.5	1.0	1.1	.2	.6	.2	.5	.9	.4	.7	.2	.3	.7	.7
Potato	307–312	.3	.3	.6	.3	.1	.3	.....	.2	1.1	.7	.4	.7	.3	.6	.8	.2	.6	.3	.1	.5	.4
Amaranthus	211–216	1.0	1.4	1.4	1.2	.8	.8	.2	1.2	1.3	1.5	.8	.8	.6	.9	1.5	.6	1.1	.3	.8	.8	1.0
Sudan grass	253–258	.5	.5	1.1	.8	.7	.9	.1	1.0	1.4	1.9	1.0	1.0	.7	1.0	1.8	.8	1.6	.8	.7	1.3	1.2
Alfalfa, E–23	193–198	2.5	2.5	3.1	2.9	2.0	2.2	1.0	3.2	3.7	4.0	2.4	2.7	1.7	2.4	2.9	2.8	3.6	1.7	1.9	2.3	2.3
Alfalfa, 162–98A1	199–204	2.0	2.2	2.7	2.5	1.7	1.9	.8	2.6	3.0	2.8	1.9	2.3	1.5	2.3	2.6	2.4	3.1	1.5	2.1	2.5	2.4

AUG. 5 TO 27

Item.	Pot No.	August.																				
		5	6–8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Evaporation (shallow tank), kgm. per sq. meter		8.41	3.40	6.28	6.46	6.36	7.02	5.58	5.43	4.91	5.88	4.80	5.32	4.88	3.46	4.10	4.13	3.61	4.50	5.82	3.47	6.04
Evaporation (deep tank) mm.		7.08	4.72	4.78	4.60	5.66	.33	4.34	4.90	3.68	4.39	5.15	4.62	3.96	4.06	4.42	3.61	5.39	3.81	5.26	1.98	4.78
Evaporation (deep tank) inches		.279	.186	.188	.181	.223	210	.171	.193	.145	.173	.203	.182	.156	.160	.174	.142	.212	.150	.207	.078	.188
Air temperature, max °C.		31.7	24.4	25.6	27.8	27.8	28.3	26.7	28.3	24.4	27.2	26.7	23.9	24.4	25.0	26.1	27.8	23.3	23.9	26.1	22.8	26.7
Air temperature, min. °C.		13.9	12.2	11.7	11.7	12.8	12.2	12.8	12.2	13.3	12.8	11.1	13.3	10.6	11.1	10.6	11.7	9.4	12.2	11.1	11.1	13.3
Air temperature integrated, mean °C.		23.3	17.8	17.8	19.4	19.4	19.4	19.4	17.8	17.8	18.9	16.7	17.2	15.0	16.7	18.3	18.3	15.6	16.7	17.2	15.6	19.4
Air temperature, max °F.		89	76	78	82	82	83	80	83	76	81	80	75	76	77	79	82	74	75	79	73	80
Air temperature, min. °F.		57	54	53	53	55	54	55	54	56	55	52	56	51	52	51	53	49	54	52	52	56
Air temperature integrated, mean °F.		74	64	64	67	67	67	67	64	64	66	62	63	59	62	65	65	60	62	63	60	67
Integrated radiation, cal. per sq. cm		953	477	892	825	727	793	815	690	672	741	628	648	469	618	754	648	497	593	570	487	773
Integrated wet-bulb depression, hr. deg. C.		169	52	92	98	96	119	94	81	60	72	42	41	41	45	74	90	61	41	82	39	105
Wind velocity. miles per hr.		5.0	3.8	3.9	3.1	4.4	5.5	2.3	4.1	3.4	3.4	4.0	4.5	3.1	6.6	1.6	4.4	3.3	6.3	5.0	2.9	3.5
Wind velocity. meters per sec.		2.2	1.7	1.7	1.4	2.0	2.5	1.0	1.8	1.5	1.5	1.8	2.0	1.4	2.9	.7	2.0	1.5	2.8	2.2	1.3	1.6
Daily transpiration, kgms.:																						
Wheat, Kubanka	1–6	1.6	.2	1.6	.1	.2	.8	.3	.....	.2	.2	.0	.1	.3	.3	.....	.....	.....	.....	.....	.....	.....
Wheat, Galgalos	7–12	1.4	.1	1.3	.3	.....	.6	.3	.....	.1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Wheat, Washington Blue-stem	13–18	2.4	.8	2.3	1.4	.8	1.8	1.3	1.0	.7	.9	.2	.4	.3	.3	.4	.2	.....	.4	.1	.....	.....
Wheat, Turkestan	19–24	1.8	.1	1.5	.9	.3	1.1	.7	.....	.4	.4	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Wheat, Marquis	103–108	1.4	.2	1.3	.8	.1	.7	.5	.....	.3	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Wheat, Kubanka	109–114	2.5	.5	1.9	1.1	.5	1.4	1.0	.3	.5	.6	.1	.3	.3	.3	.3	.2	.....	.....	.....	.....	.....
Wheat, Preston	127–132	2.8	.7	2.1	1.5	1.0	1.9	1.5	.6	1.0	.9	.4	.5	.5	.3	.7	.3	.....	.3	.....	.....	.....
Oat, Swedish Select	139–144	4.0	.7	3.1	1.4	.8	1.5	1.2	.3	.8	.8	.1	.3	.4	.3	.....	.....	.....	.....	.....	.....	.....
Oat, Burt	145–150	1.7	.2	1.3	.6	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Barley, Hannchen	133–138	1.3	.....	1.0	.3	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Rye, Spring	151–156	1.6	.4	1.5	1.0	.3	.8	1.0	.1	.9	.5	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Flax, North Dakota (C. I. 13)	157–162	1.9	.1	1.4	.8	.1	.6	.7	.....	.6	.4	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Flax, North Dakota (C. I. 19)	187–192	2.4	.6	2.2	1.0	.3	1.4	1.1	.3	.8	.6	.0	.2	.3	.2	.4	.1	.....	.2	.2	.....	.....
Flax, Smyrna	163–168	2.9	.8	2.4	1.2	.5	1.8	1.6	.2	.8	.4	.1	.3	.4	.1	.1	.3	.....	.2	.0	.....	.....
Cowpea	217–222	1.5	.4	1.7	.9	.8	1.3	1.4	1.0	1.0	1.1	1.0	1.1	.6	.7	.8	.4	.1	.5	.5	.2	1.0
Millet	223–228	1.7	.....	1.8	1.1	1.1	1.7	1.1	.....	1.1	1.1	.5	.9	.6	.5	1.1	.7	.0	.7	.7	.4	1.3
Sorghum	235–240	1.5	.6	1.5	.9	.5	1.0	1.0	.5	1.0	.7	.5	.7	.5	.3	.6	.5	.....	.6	.3	.2	1.1
Corn	241–246	1.0	.1	1.2	.5	.3	.8	.4	.2	.7	.5	.2	.4	.3	.2	.5	.4	.1	.5	.3	.1	.8
Potato	307–312	.3	.....	1.2	.3	.2	.2	.6	.....	.5	.5	.2	.1	.3	.0	.5	.4	.1	.4	.1	.0	.7
Amaranthus	211–216	1.4	C.	.6	.....	.....	.0	.1	.....	.3	.2	.0	.1	.1	.0	.2	.2	.1	.3	.2	.1	.5
Sudan grass	253–258	1.9	.6	1.8	.9	.6	1.3	1.0	.8	1.0	.5	.7	.6	.3	.2	.6	.5	.1	.4	.5	.1	C.
Alfalfa, E–23	193–198	3.6	C.	.8	.0	.1	.3	.5	.2	.7	.8	.6	.8	.5	.9	1.3	1.3	.7	1.1	1.4	.8	2.3
Alfalfa, 162–98A1	199–204	3.4	C.	.6	.....	.1	.3	.5	.1	.7	.9	.6	.7	.7	1.0	1.4	1.3	.9	1.2	1.5	.8	2.1

TABLE III.—*Measurements of environmental factors and daily transpiration, May 22 to September 20, 1915*—Continued

AUG. 28 TO SEPT. 20

Item.	Pot No.	August.				September.															
		28	29	30	31	1	2	3	4	5	6	7	8	9	10–11	12–13	14–15	16	17	18	19	20
Evaporation (shallow tank), kgm. per sq. meter		5.81												9.37	6.06	5.93	4.71	6.94	6.51	8.63	7.28	5.32
Evaporation (deep tank) mm		6.22	4.09	5.84	4.93	8.18	7.77	7.46	5.44	4.52	4.85	7.75	2.01	6.93	4.39	4.85	4.47	3.30	3.66	6.02	5.18	4.98
Evaporation (deep tank) inches		.245	.161	.230	.194	.322	.306	.294	.214	.178	.191	.305	.079	.273	.173	.191	.176	.130	.144	.237	.204	.196
Air temperature, max., °C		24.4	22.2	26.1	34.4	33.3	28.9	28.9	27.8	23.9	26.7	31.1	20.6	25.6	25.0	25.0	15.6	25.0	28.3	27.2	30.0	17.2
Air temperature, min., °C		3.9	5.6	9.4	13.3	7.2	10.6	11.7	12.8	8.9	11.7	11.1	10.6	8.3	8.3	6.1	7.8	10.0	7.8	13.3	5.0	2.8
Air temperature, integrated mean, °C		14.4	13.3	17.8	22.8	19.4	20.6	20.0	19.4	14.4	17.8	18.9	13.3	16.7	16.1	13.9	10.6	15.6	17.2	18.9	17.8	11.1
Air temperature, max., °F		76	72	79	94	92	84	84	82	75	80	88	69	78	77	77	60	77	83	81	86	63
Air temperature, min., °F		39	42	49	56	45	51	53	55	48	53	52	51	47	47	43	46	50	46	56	41	37
Air temperature, integrated mean, °F		58	56	64	73	67	69	68	67	58	64	66	56	62	61	57	51	60	63	66	64	52
Integrated radiation, cal. per sq. cm		548	825	805	776	822	808	758	645	591	729	662	432	706	515	600	618	790	731	734	603	813
Integrated wet-bulb depression, hr. deg. C		140	123	111	146	223	167	124	121	62	63	.....	48	84	107	53	89	113	163	134	183	102
Wind velocity miles per hour		5.4	6.9	5.8	3.9	5.8	8.7	10.0	6.8	5.3	5.7	7.2	5.5	10.9	6.8	7.0	5.7	3.9	2.5	7.0	4.1	4.5
Wind velocity meters per sec.		2.4	3.1	2.6	1.7	2.6	3.9	4.5	3.0	2.4	2.5	3.2	2.5	4.9	3.0	3.1	2.5	1.7	1.1	3.1	1.8	2.0
Daily transpiration, kgm.:																						
Cowpea	217–222	.5	.3	.....	.3	.6	.4	.2	.1	.....	.1	.3	0	.....	.....	.....	.....	.....	.....	.....	.....	.....
Millet	223–228	.8	.6	.5	1.0	1.2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Sorghum	235–240	.5	.5	.4	.9	1.4	1.1	.8	.7	.2	.6	1.3	.1	.8	.4	.5	.....	.....	.....	.....	.....	.....
Corn	241–246	.5	.1	.1	.5	.6	.4	.2	.3	.....	.2	.5	.1	.2	.2	.4	.....	.....	.....	.....	.....	.....
Potato	307–312	.2	.1	.1	.3	.3	.4	.2	.2	.1	.1	.4	.1	.1	.1	.4	.....	.....	0	.7	.2	.1
Amaranthus	211–216	.4	.1	.....	.2	.4	.3	.4	.1	.1	.2	.4	.1	.2	.2	.2	0	.2	.3	.5	.3	.1
Sudan grass	253–258	.2	.3	.....	.1	.3	.2	.1	.3	.1	.1	.5	.1	.3	.2	.3	.1	.1	.2	.9	.3	.1
Alfalfa, E–23	193–198	2.3	1.4	1.3	2.7	3.7	3.0	2.1	2.6	1.4	2.6	3.4	1.0	1.8	1.8	1.2	.5	1.6	2.2	2.7	2.7	1.7
Alfalfa, 162–98A1	199–204	2.4	1.2	1.3	2.6	3.4	3.0	2.0	2.3	1.3	2.3	3.0	1.0	2.1	1.8	1.3	.7	1.5	2.0	2.6	2.5	1.9

TABLE IV.—*Period of growth, yield, and water requirement of plants used in 1915 transpiration measurements*

Crop.	Variety.	Botanical name.	Period of growth.	Pot No.	Mean dry matter.	Mean water.	Mean grain.	Water requirements based on dry matter.
					Gm.	*Kgm.*	*Per cent.*	
Wheat	Kubanka (C. I. 1440)	*Triticum durum*	May 22–Aug. 21	1–6	209	85	32	405±6
Do	Galgalos (C. I. 2398)	*Triticum aestivum*	May 22–Aug. 16	7–12	168	81	32	481±4
Do	Washington Bluestem (C. I. 4067).	do	May 22–Aug. 26	13–18	215	105	15	491±4
Do	Turkestan (C. I. 4087)	do	May 22–Aug. 18	19–24	219	111	30	505±3
Do	Marquis (C. I. 3641)	do	May 22–Aug. 16	103–108	208	88	33	424±3
Do	Kubanka (C. I. 1440)	*Triticum durum*	May 24–Aug. 24	109–114	267	108	34	406±3
Do	Preston (C. I. 2958)	*Triticum aestivum*	May 28–Aug. 26	127–132	279	126	26	453±6
Oat	Swedish Select (C. I. 134)	*Avena sativa*	May 28–Aug. 21	139–144	332	148	41	448±10
Do	Burt (C. I. 293)	do	May 28–Aug. 11	145–150	233	103	38	445±5
Barley	Hannchen (C. I. 531)	*Hordeum distichon*	do	133–138	262	106	43	404±11
Rye	Spring (C. I. 73)	*Secale cereale*	May 28–Aug. 17	151–156	203	95	32	469±8
Flax	North Dakota (C. I. 13)	*Linum usitatissimum*	June 1–Aug. 17	157–162	149	86	29	579±10
Do	North Dakota (C. I. 19)	do	June 1–Aug 26	187–192	186	114	26	615± 7
Do	Smyrna (C. I., 30)	do	do	163–168	182	121	24	663±16
Cowpea	S. P. I., 29282	*Vigna sinensis*	June 4–Sept. 9	217–222	128	53	33	413± 5
Millet	Kursk (S. P. I., 34771)	*Chaetochloa italica*	June 26–Sept. 2	223–228	256	52	31	202± 1
Sorghum	Minnesota Amber (A. D. I., 341–13.)	*Andropogon sorghum*	June 26–Sept. 14	235–240	203	41	19	203± 3
Corn	Northwestern Dent	*Zea mays*	do	241–246	112	28	.....	253± 7
Potato	Irish Cobbler	*Solanum tuberosum*	July 1–Sept. 25	307–312	67	22	.....	329± 4
Amaranthus:								
First crop		*Amaranthus retroflexus*	June 26–Aug. 6	211–216	129	31	.....	239± 3
Second crop			Aug. 6–Sept. 21	211–216	30	6	.....	188± 4
Combined			June 26–Sept. 21	211–216	159	36	.....	229± 3
Sudan grass:								
First crop		*Andropogon sorghum aethiopicus.*	June 26–Aug. 28	253–258	176	43	.....	246± 3
Second crop	S. P. I., 25071		Aug. 29–Sept. 24	253–258	15	6	.....	424±12
Combined			June 26–Sept. 24	253–258	190	49	.....	260± 3
Alfalfa:								
First crop		*Medicago sativa*	June 17–Aug. 6	193–198	133	86	.....	646±14
Second crop	Grimm (A. D. I., E-23)		Aug. 7–Sept. 21	193–198	83	65	.....	773± 6
Combined			June 17–Sept. 21	193–198	217	151	.....	696±10
Alfalfa:								
First crop			June 17–Aug. 6	199–204	115	70	.....	619±13
Second crop	Grimm (A. D. I., 162–98–A–1)	do	Aug. 7–Sept. 21	199–204	78	60	.....	782±16
Combined			June 17–Sept. 21	199–204	192	131	.....	685±13

COMPARISON OF THE TRANSPIRATION OF THE DIFFERENT CROPS

The graphs in figures 2 and 3 illustrate in a striking manner the great fluctuations in the water required daily by plants to maintain normal growth. During the period from July 8 to 10, 1914, for example, the wheats under observation required about three times as much water each day as during the period from July 17 to 19. In 1914 the maximum rate of transpiration of the series as a whole occurred about July 9, at which period the grains were headed, the legumes were in bloom or coming into bloom, and corn was beginning to tassel.

Alfalfa, Sudan grass, and amaranthus, of which several cuttings were made from the same root system, showed a continuous increase in the transpiration rate up to the time of cutting. The transpiration of Minnesota Amber sorghum, Algeria corn, and lupine was relatively uniform from about July 9 to near the end of the growth season. Among the small grains barley and rye showed the least change in the transpiration rate. The grain crops were harvested at the stage when similar crops in the field are cut with the binder, and it is interesting to note at this time transpiration was approximately one-fourth to one-half the maximum rate.

The season of 1915, like that of 1914, shows a nearly uniform evaporation rate throughout the more active growth period if the daily fluctuations are ignored. The season was very rainy. This is reflected in the radiation graph which is far more irregular than in 1914, but shows the same gradual decline as the season advances.

The fluctuations of the transpiration graphs give evidence again of the great variation in the daily quantity of water required to maintain normal growth, as is shown by comparing the transpiration during the period from July 21 to 23 with the adjacent three-day periods.

While the fluctuations of the different crops from day to day are similar, marked differences in the pitch of the graphs are noticeable as the season advances. The short season crops in general show a gradual increase in transpiration from seedtime to a little past the middle of the growth period and then an equally gradual decline to harvest.

The idea is often advanced that wheat and similar crops increase their water demand suddenly at or just before the time of heading. The measurements of the writers, however, lend no support to this conclusion. (See transpiration-evaporation ratios.) Aside from fluctuations due to weather the transpiration increases uniformly during this period.

WATER LOSS DURING PERIODS OF MAXIMUM TRANSPIRATION

It has already been shown in the case of annual crop plants that the transpiration rises to a maximum near the middle of the growth period and then decreases until the plants are harvested. This is especially true of grain crops. On the other hand, the transpiration of perennial forage crops, such as alfalfa, increases steadily to a maximum at the

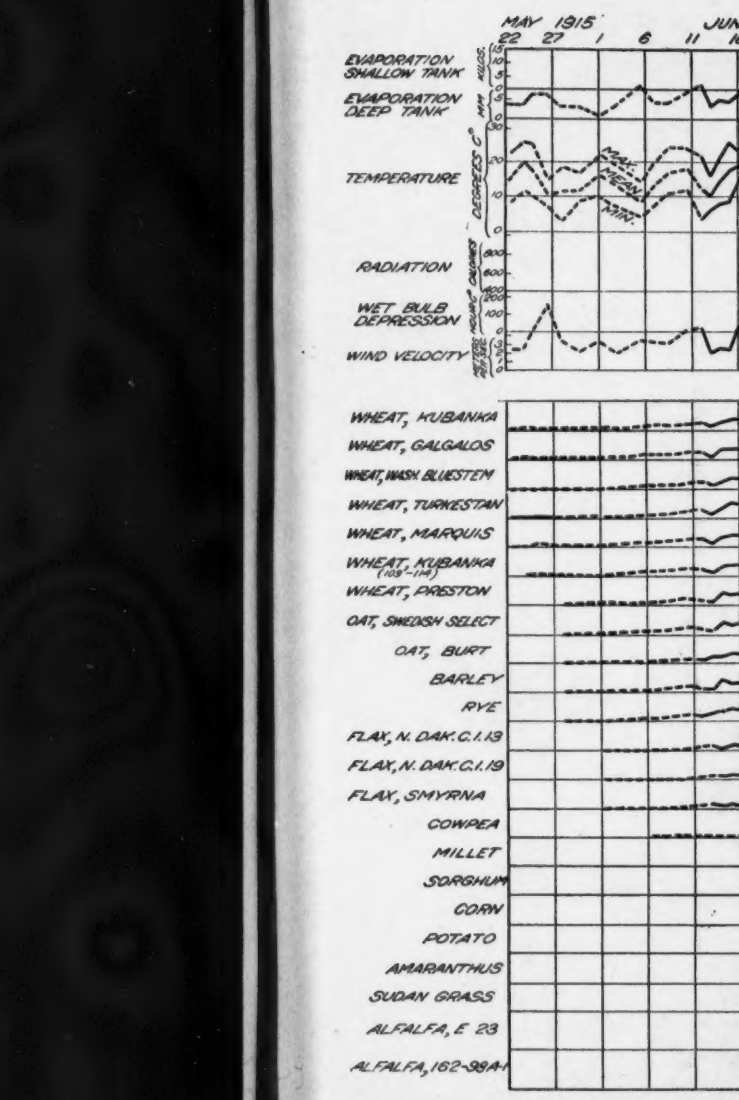


FIG. 3.—Graphs showing the daily intensity of environm
square meter. The evaporation from the large tank
square centimeter on a surface normal to the sun's ra
space between the base (zero) lines for each crop repr
that the crop was cut and was followed by a new gr
leaves dying.

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ty of environmental factors and the daily transpiration of 23 crops for the year 1915. The evaporation from the small tank is expressed in kilograms per he large tank is given in millimeters. The temperatures are expressed in degrees centigrade; the total radiation for the day in small calories per to the sun's rays; the wet-bulb depression in hour degrees C.; the wind velocity in meters per second. The transpiration is given in kilograms, the each crop representing 3 kgm., except for alfalfa, the base line of which is 5 kgm. below that of the crop above. The letter *C* in the graph indicates l by a new growth from the established root system. *S* signifies that the plants were forming shoots; *H*, heading; *F*, flowering; and *D*, lower

4.)

time of cutting. Various crops show their individuality by departing more or less from these types. By comparing the transpiration of two crops during any period with their total transpiration the relative demand of the crops for water during this period can be shown. Such a comparison is given in Table V for the 10-day period in 1914 from July 7 to 16, inclusive, which represents a period of maximum transpiration activity.

TABLE V.—*A comparison of transpiration during the 10-day period July 7 to 16, 1914, with total transpiration of crop*

Crop	Total transpiration.	Transpiration during 10-day period July 7–16.	
		Actual.	Percentage of total.
	Kgm.	*Kgm.*	
Wheat, Kubanka	160	40.0	25
Wheat, Galgalos	186	46.9	25
Oat, Swedish	158	43.4	27
Oat, Burt	154	40.5	26
Barley	91	22.0	24
Rye	121	30.5	25
Cowpea	112	31.7	28
Lupine	76	17.2	23
Millet, Kursk	89	23.9	27
Millet, Siberian	100	25.7	26
Corn, Northwestern Dent	112	27.5	25
Corn, Algeria	137	26.9	20
Sorghum, Minnesota Amber	130	26.8	21
Sorghum, Dakota Amber	126	26.2	21
Sudan grass (in inclosure)	110	29.0	26
Sudan grass (in open)	88	21.9	25

The relative transpiration of the small grains during this period was very nearly the same, ranging from 24 to 27 per cent of the total transpiration. This group, including the millets, shows a uniformity in this respect which is remarkable. Sudan grass, grown both outside and inside the screened inclosure, showed a relative transpiration loss during this period agreeing closely with the small grains. The same is true with Northwestern Dent corn, an early-maturing variety. Algeria corn and the two varieties of sorghum, on the other hand, show a lower relative transpiration during this period, owing to the fact that they mature later than the other crops considered.

Similar data covering a 10-day period in August are presented in Table VI. All of the crops show a lower transpiration than during the July period, except Sudan grass and Algeria corn, which had not yet begun to ripen.

Amaranthus and the alfalfas were cut the second time at the end of this period. The ratios show that nearly one-half of the total water used by the alfalfas in the production of the second crop was transpired during this 10-day period. In the case of Amaranthus the percentage was even greater.

TABLE VI.—*A comparison of transpiration during the 10-day period August 2 to 11, 1914, with total transpiration of crop*

Crop.	Total transpiration.	Transpiration during 10-day period Aug. 2–11.	
		Actual.	Percentage of total.
	Kgm.	*Kgm.*	
Cowpea	112	10.4	9
Lupine	76	12.4	16
Millet, Kursk	89	15.2	17
Millet, Siberian	100	16.5	17
Corn, Northwestern Dent	112	14.4	13
Corn, Algeria	137	27.0	20
Sorghum, Minnesota Amber	130	23.4	18
Sorghum, Dakota Amber	126	21.6	17
Sudan grass (in inclosure)	110	26.8	24
Sudan grass (in open)	88	24.4	28
Amaranthus	16	9.4	59
Alfalfa, Grimm, E23–20–52	60	28.3	47
Alfalfa, Grimm, E23	70	33.2	47
Alfalfa, Grimm, E23 (in open)	67	32.6	49
Alfalfa, Grimm, 162–98A	118	52.9	45

Similar determinations of the transpiration of different crops in 1915 during a 10-day period from July 7 to 16 are given in Table VII. The transpiration during this period ranged from 23 to 31 per cent of the total. In other words, one-fourth or more of the total water used by these crops was transpired during these 10 days. With the exception of the flax varieties the crops showing the highest transpiration during this period were those which matured earliest.

TABLE VII.—*A comparison of transpiration during the 10-day period July 7 to 16, 1915, with total transpiration of crop*

Crop.	Total transpiration.	Transpiration during 10-day period July 7–16.	
		Actual.	Percentage of total.
	Kgm.	*Kgm.*	
Wheat, Kubanka	85	20.5	24
Wheat, Galgalos	81	21.7	27
Wheat, Washington Bluestem	105	24.1	23
Wheat, Turkestan	111	29.0	26
Wheat, Marquis	88	22.6	25
Wheat, Kubanka	108	24.6	23
Wheat, Preston	126	28.6	23
Oat, Swedish Select	148	38.3	26
Oat, Burt	103	30.3	29
Barley, Hannchen	106	31.5	30
Rye, Spring	95	22.8	24
Flax, North Dakota (C. I. 13)	86	25.2	29
Flax, North Dakota (C. I. 19)	114	34.9	31
Flax, Smyrna	121	33.4	28

Corresponding determinations for a later 10-day period in 1915, July 27 to August 5, are given in Table VIII, which includes all crops in the 1915 daily transpiration measurements. The earlier maturing crops considered in the preceding table (VII) show a transpiration during this period amounting to 16 per cent of the total, compared with 26 per cent during the July period. Many of the crops were harvested soon after the termination of the July-August period, but the data given in Table VIII show that they were still transpiring actively.

TABLE VIII.—*A comparison of transpiration during the 10-day period July 27 to August 5, 1915, with total transpiration of crop*

Crop.	Total transpiration.	Transpiration during 10-day period July 27–Aug. 5.	
		Actual.	Percentage of total.
	Kilograms.	*Kilograms.*	
Wheat, Kubanka	85	12.6	15
Wheat, Galgalos	81	10.8	13
Wheat, Washington Bluestem	105	17.1	16
Wheat, Turkestan	111	15.1	14
Wheat, Marquis	88	13.2	15
Wheat, Kubanka	108	17.9	17
Wheat, Preston	126	20.4	16
Oat, Swedish Select	148	25.8	17
Wheat, Burt	103	15.2	15
Barley, Hannchen	106	13.8	13
Rye, spring	95	13.1	14
Flax, North Dakota (C. I. 13)	86	15.6	18
Flax, North Dakota (C. I. 19)	114	20.2	18
Flax, Smyrna	121	19.8	16
Cowpea	53	11.5	22
Millet	52	11.5	22
Sorghum	41	8.4	20
Corn	28	5.6	20
Potato	22	4.1	19
Amaranthus	31	9.0	29
Sudan grass	43	11.8	27
Alfalfa, E23	86	25.2	29
Alfalfa, 162–98A1	70	23.8	34

The alfalfa and amaranthus measurements given in Table VIII represent the first crops, which were harvested at the close of the period. These plants, together with Sudan grass, show a markedly higher transpiration loss than the small grains.

LOSS OF WATER DURING THE MAXIMUM TRANSPIRATION PERIOD PER UNIT OF DRY MATTER HARVESTED

MEAN DAILY TRANSPIRATION PER GRAM OF DRY MATTER HARVESTED

It is not possible in the case of the grain crops to determine directly the maximum transpiration per unit of dry matter without sacrificing the crop in order to find the dry weight. Such calculations can, however, be made upon the basis of the dry weight of the crop at maturity, which from a practical standpoint is of more importance than the former determination. Computations of this kind are presented in Tables IX to XII for the 10-day periods just considered.

Reference to Table IX will show that during the transpiration period July 7 to 16, 1914, the small grains were transpiring from 12 to 16 gm. of water per day per gram of dry matter harvested; cowpea and lupine, 19 gm.; and millet, sorghums, and corn, 6 to 9 gm. These quantities are approximately proportional to the water requirement of the crops.

TABLE IX.—*Loss of water per unit of dry matter harvested during the maximum transpiration period July 7 to 16, 1914* [a]

Crop.	Dry matter.	Mean daily transpiration, July 7–16.		Hourly transpiration during midday per gram of dry matter.	Daily loss of water per ton of dry matter per acre.
		Actual.	Per gram of dry matter.		
	Grams.	*Kilograms.*	*Grams.*	*Grams.*	*Acre-inches.*
Wheat, Kubanka	306	4.00	13.1	1.3	0.11
Wheat, Galgalos	298	4.69	15.7	1.6	.14
Oat, Swedish	264	4.34	16.4	1.6	.15
Oat, Burt	251	4.05	16.1	1.6	.14
Barley	182	2.20	12.1	1.2	.11
Rye	195	3.05	15.6	1.6	.14
Cowpea	170	3.17	18.6	1.9	.16
Lupine	90	1.72	19.1	1.9	.17
Millet, Kursk	301	2.39	7.9	.8	.07
Millet, Siberian	318	2.57	8.1	.8	.07
Corn, Northwestern Dent	304	2.75	9.0	.9	.08
Corn, Algeria	417	2.69	6.5	.7	.06
Sorghum, Minnesota Amber	457	2.68	5.9	.6	.05
Sorghum, Dakota Amber	427	2.62	6.1	.6	.05

[a] Mean daily evaporation, 12.3 kgm. per square meter.

Sudan grass during a 10-day period in August immediately preceding the first cutting showed an average transpiration loss of from 9 to 11 gm. per day per gram of dry matter harvested (Table X). Amaranthus and alfalfa were cropped for the second time at the end of this period. Amaranthus showed a transpiration loss of 17 gm. per day per gram of dry matter produced, while the alfalfas transpired from 36 to 56 gm. per day per gram of dry matter harvested. The Sudan grass and alfalfa grown outside the screened inclosure showed a transpiration from 27 to 30 per cent higher than the same crops inside the inclosure. This cor-

responds very closely with previous determinations of the influence of the inclosure on the water requirement.[1]

TABLE X.—*Loss of water per unit of dry matter harvested during the maximum transpiration period, August 2 to 11, 1914* [a]

Crop.	Dry matter.	Mean daily transpiration Aug. 2–11.		Hourly transpiration during midday per gram of dry matter.	Daily loss of water per ton of dry matter per acre.
		Actual.	Per gram of dry matter.		
	Grams.	*Kilograms.*	*Grams.*	*Grams.*	*Acre-inches.*
Suda.. grass (in inclosure)	301	2.68	8.9	0.9	0.08
Sudan grass (in open)	216	2.44	11.3	1.1	.10
Amaranthus	54	.94	17.4	1.7	.15
Alfalfa, E23–20–52	66	2.83	42.9	4.3	.38
Alfalfa, E23	77	3.32	43.1	4.3	.38
Alfalfa, E23 (in open)	58	3.26	56.2	5.6	.50
Alfalfa, 162–98A	146	5.29	36.2	3.6	.32

[a] Mean daily evaporation 12 kgm. per square meter.

Reference has already been made to the fact that the water requirement in 1915 was much lower than in 1914. The daily transpiration loss of the small grains during a 10-day period from July 7 to 16, 1915, ranged from 9 to 13 gm. per gram of dry matter harvested (Table XI). Flax, which has a much higher water requirement than the small grains, showed during this period a daily loss of from 17 to 19 gm. of water per gram of dry matter harvested.

TABLE XI.—*Loss of water per unit of dry matter harvested during the maximum transpiration period July 7 to 16, 1915* [a]

Crop.	Dry matter.	Mean daily transpiration July 7–16.		Hourly transpiration during midday per gram of dry matter.	Daily loss of water per ton of dry matter per acre.
		Actual.	Per gram of dry matter.		
	Grams.	*Kilograms.*	*Grams.*	*Grams.*	*Acre-inches.*
Wheat, Kubanka	209	2.05	9.8	1.0	0.09
Wheat, Galgalos	168	2.17	12.9	1.3	.11
Wheat, Washington Bluestem	215	2.41	11.2	1.1	.10
Wheat, Turkestan	219	2.90	13.2	1.3	.12
Wheat, Marquis	208	2.26	10.9	1.1	.10
Wheat, Kubanka	267	2.46	9.2	.9	.08
Wheat, Preston	279	2.86	10.2	1.0	.09
Oat, Swedish Select	332	3.83	11.5	1.2	.10
Oat, Burt	233	3.03	13.0	1.3	.12
Barley	262	3.15	12.0	1.2	.11
Rye	203	2.28	11.2	1.1	.10
Flax, North Dakota (C. I. 13)	149	2.52	16.9	1.7	.15
Flax, North Dakota (C. I. 19)	186	3.49	18.8	1.9	.17
Flax, Smyrna	182	3.34	18.4	1.8	.16

[a] Mean daily evaporation, 7.3 kgm. per square meter.

[1] Briggs, L. J., and Shantz, H. L. Relative water requirement of plants. *In* Jour. Agr. Research, v. 3, no. 1, p. 1–64, 1 fig. pl. 1–7. 1914. Literature cited, p. 62–63.

Similar measurements for other crops during a later 10-day period in 1915 (Table XII) showed a marked reduction in the daily transpiration rate compared with the preceding year. The evaporation rate during the 1915 period was only about one-half that in 1914. The transpiration rate of the alfalfas during the 1915 period was also approximately one-half that observed in 1914.

TABLE XII.—*Loss of water per unit of dry matter harvested during the maximum transpiration period July 27 to August 5, 1915* [a]

Crop.	Dry matter.	Mean daily transpiration July 27–Aug. 5, 1915.		Hourly transpiration during midday per gram of dry matter.	Daily loss of water per ton of dry matter per acre.
		Actual.	Per gram of dry matter.		
	Grams.	*Kilograms.*	*Grams.*	*Grams.*	*Acre-inches.*
Cowpea	128	1. 15	9. 0	0. 9	0. 08
Millet	256	1. 15	4. 5	. 5	. 04
Sorghum	203	. 84	4. 1	. 4	. 04
Corn	112	. 56	5. 0	. 5	. 04
Potato	67	. 41	6. 1	. 6	. 05
Amaranthus	129	. 90	7. 0	. 7	. 06
Sudan grass	176	1. 18	6. 7	. 7	. 06
Alfalfa, E23	133	2. 52	18. 9	1. 9	. 17
Alfalfa, 162–98A1	115	2. 38	20. 7	2. 1	. 18

[a] Mean daily evaporation, 6.2 kgm. per square meter.

HOURLY TRANSPIRATION DURING MIDDAY PER GRAM OF DRY MATTER HARVESTED

An examination of the graphs of hourly transpiration on clear days [1] shows that the transpiration during one hour at or near midday in midsummer is approximately one-tenth of the total transpiration for the day. The hourly transpiration of different crops has been calculated on this basis for the midday hours during the 10-day maximum transpiration periods considered above (Tables IX to XII). In 1914 the midday transpiration of the small grains ranged from 1.2 gm. per hour per gram of dry matter for barley to 1.6 gm. for wheat, oat, and rye (Table IX). In other words, a crop of oat yielding 1 ton of dry matter per acre would have lost 1.6 tons of water per acre per hour during the midday hours of its maximum transpiration period.

Cowpea and lupine lost each hour during midday an amount of water equal to 1.9 times the dry weight of the crop (Table IX). Millet, corn, and sorghum transpired at a much slower rate than the other crops here considered, the hourly loss of sorghum being 0.6, millet 0.8, and corn 0.7 to 0.9 that of its dry weight.

[1] Briggs, L. J., and Shantz, H. L. Hourly transpiration rate on clear days as determined by cyclic environmental factors. *In* Jour. Agr. Research, v. 5, no. 14, p. 583–650, 22 fig., pl. 53–55. 1916. Literature cited, p. 648–649.

During the August transpiration period in 1914 (Table X) the alfalfas showed an hourly transpiration loss near midday of from 3.6 to 5.6 gm. per gram of dry matter. In other words, during the last third of the growth period the alfalfa crops lost during each midday hour an amount of water ranging from 3.6 to 5.6 times the dry weight of the crop.

The conditions in 1915, as has already been mentioned, were less severe than in 1914. The evaporation during the July maximum transpiration period in 1915 was only 60 per cent of that during the corresponding period in 1914. The transpiration loss of the small grains each hour during midday was approximately equal to the dry weight of the crop (Table XI). The transpiration loss of the flax varieties was nearly twice as great.

During the second transpiration period considered in 1915 (Table XII), the midday loss was still further reduced, being approximately one-half that observed in 1914.

DAILY LOSS OF WATER IN ACRE-INCHES PER TON OF DRY MATTER HARVESTED PER ACRE

From a practical standpoint it is desirable to express the daily transpiration loss in terms of acre-inches of water per ton of dry matter produced per acre. This is given in the last column of Tables IX to XII. A wheat crop yielding a ton of dry matter (grain and straw combined) would thrash approximately 12 bushels of wheat. Such a crop at Akron in 1914 would have used approximately 0.13 acre-inch of water each day during its maximum transpiration period. Millet, corn, and sorghum required approximately one-half this amount per ton of dry matter, while the alfalfas during their maximum transpiration period required the equivalent of a rainfall of from 0.3 to 0.5 inch per day per ton of dry matter produced per acre.

LOSS OF WATER DURING MAXIMUM TRANSPIRATION PERIOD PER SQUARE METER OF PLANT SURFACE

The surface area of the plant tissues of the different crops included in the transpiration measurements was determined from a selected sample of the plants in one pot of each set. The ratio of the portion selected to the whole crop was found by comparing the green weight of the sample (taken immediately after cutting) with the green weight of the whole crop. The area of the selected portion was determined by one of the following methods: (1) By direct measurement of the length and breadth (or diameter) of the leaves or stems; (2) by pasting the leaf and flower parts on surgeon's tape and determining the area by measurements; (3) by prints of the pasted leaves on squared photographic paper, the area being determined either by direct counts of the squares on the paper or by a planimeter. From the total area of the sample and

the ratio of the weights the mean surface area per pot was computed. The area measurements were made at harvest time and include the area of matured leaves as well as the fresh leaves and stems. The maximum transpiring area is therefore represented in these measurements (Tables XIII to XVI).

TABLE XIII.—*Transpiration per square meter of plant surface during the 10-day period July 7 to 16, 1914*[a]

Crop.	Plant surface.	Daily transpiration July 7–16.		Hourly transpiration per square meter of plant surface during midday.	Ratio of transpiration per square meter to evaporation per square meter.
		Actual.	Per square meter of plant surface.		
	Sq. meters.	*Kgm.*	*Kgm.*	*Gm.*	
Wheat, Kubanka	2.45	4.00	1.63	163	0.13
Wheat, Galgalos	2.68	4.69	1.75	175	.14
Oat, Swedish	3.42	4.34	1.27	127	.10
Oat, Burt	2.46	4.05	1.65	165	.13
Barley	1.95	2.20	11.3	113	.09
Rye	1.99	3.05	1.53	153	.12
Millet, Kursk	3.15	2.39	.76	76	.06
Millet, Siberian	4.20	2.57	.61	61	.05
Sorghum, Dakota Amber	1.76	2.62	1.49	149	.12

[a] Mean daily evaporation=12.3 kgm. per square meter. Hourly evaporation during midday=1,230 gm. per square meter.

TABLE XIV.—*Transpiration per square meter of plant surface during the 10-day period August 2 to 11, 1914*[a]

Crop.	Plant surface.	Daily transpiration Aug. 2–11.		Hourly transpiration per square meter of plant surface during midday.	Ratio of transpiration per square meter to evaporation per square meter.
		Actual.	Per square meter of plant surface.		
	Sq. meters.	*Kgm.*	*Kgm.*	*Gm.*	
Sudan grass (in inclosure)	3.27	2.68	0.82	82	0.07
Sudan grass (in open)	1.90	2.44	1.28	128	.11
Amaranthus	.67	.94	1.40	140	.12
Alfalfa, E23–20–52	1.71	2.83	1.66	166	.14
Alfalfa, E23	2.08	3.32	1.59	159	.13
Alfalfa, E23 (in open)	.95	3.26	3.43	343	.29
Alfalfa, 162–98A	3.37	5.29	1.57	157	.13

[a] Mean daily evaporation=12 kgm. per square meter. Hourly evaporation during midday=1,200 gm. per square meter.

TABLE XV.—*Transpiration per square meter of plant surface during the 10-day period July 7 to 16, 1915* [a]

Crop.	Plant surface.	Daily transpiration July 7–16.		Hourly transpiration per square meter of plant surface during midday.	Ratio of transpiration per square meter to evaporation per square meter.
		Actual.	Per square meter of plant surface.		
	Sq. meters.	*Kgm.*	*Kgm.*	*Gm.*	
Wheat, Kubanka	1.97	2.05	1.04	104	0.14
Wheat, Galgalos	1.47	2.17	1.48	148	.20
Wheat, Washington Bluestem	2.57	2.41	.94	94	.13
Wheat, Turkestan	2.10	2.90	1.38	138	.19
Wheat, Marquis	1.78	2.26	1.27	127	.17
Wheat, Kubanka	2.16	2.46	1.14	114	.16
Wheat, Preston	3.70	2.86	.77	77	.11
Oat, Swedish Select	2.82	3.83	1.36	136	.19
Oat, Burt	1.95	3.03	1.55	155	.21
Barley	1.74	3.15	1.81	181	.25
Rye	1.50	2.28	1.52	152	.21
Flax, North Dakota (C. I. 13)	1.49	2.52	1.69	169	.23
Flax, North Dakota (C. I. 19)	2.73	3.49	1.28	128	.18
Flax, Smyrna	3.54	3.34	.94	94	.13

[a] Mean daily evaporation=7.3 kgm. per square meter. Hourly evaporation during midday 730 gm. per square meter.

TABLE XVI.—*Transpiration per square meter of plant surface during the 10-day period July 27 to August 5, 1915* [a]

Crop.	Plant surface.	Daily transpiration July 27–Aug. 5.		Hourly transpiration per square meter of plant surface during midday.	Ratio transpiration per square meter to evaporation per square meter.
		Actual.	Per square meter of plant surface.		
	Sq. meters.	*Kgm.*	*Kgm.*	*Gm.*	
Cowpea	2.14	1.15	0.54	54	.08
Millet, Kursk	2.20	1.15	.52	52	.08
Sorghum	1.09	.84	.77	77	.12
Corn	.97	.56	.58	58	.09
Amaranthus	1.71	.90	.53	53	.09
Sudan grass	2.41	1.18	.49	49	.08
Alfalfa, E23	4.53	2.52	.56	56	.09
Alfalfa, 162–98A1	2.86	2.38	.83	83	.13

[a] Mean daily evaporation=6.2 kgm. per square meter. Hourly evaporation during midday=620 gm. per square meter.

The mean daily transpiration of the small-grain crops during the maximum transpiration period in 1914 (Table XIII) was 1.49±0.08 kgm. per square meter, and in 1915 (Table XV) 1.46±0.07 kgm. per square meter. The evaporation during the 1915 period was only 59 per cent of that observed during the corresponding period in 1914. While the transpiration periods selected were the same (July 7–16), the crops in 1914 were relatively more advanced showing evidences of ripening in some cases. This appears to be responsible, in part at least, for the observed agreement in the transpiration rate during the two years, although it is of course possible that under the weather conditions prevailing in 1915 a morphological adjustment took place, which increased the transpiration coefficient per unit area.

During the August transpiration period of 1914 the transpiration rate per square meter of plant surface (Table XIV) ranged from 81 gm. per hour for Sudan grass to 166 gm. for a variety of Grimm alfalfa, these plants being grown in the screened inclosure. The same plants grown in the open showed a transpiration loss of from 128 to 343 gm. of water per square meter of surface per hour. The water requirement of Sudan grass in the inclosure was 10 per cent below that of the crop grown in the open, while in the case of alfalfa the inclosure reduced the water requirement 22 per cent (Table II). The reduction in transpiration per unit area of the crops grown inside the inclosure is over twice that indicated from the water-requirement measurements. Here, again, there is an indication of a morphological adjustment resulting from the difference in exposure.

Periods of maximum transpiration may be due to extreme weather conditions or to the transpiration coefficient having reached its maximum or to both. It would appear that the maximum transpiration period of the small grains in 1914 was determined largely by weather conditions, since it falls rather late in the period of growth, and some of the grains had already begun to ripen. In 1915 this period corresponds more nearly to the period of maximum transpiration coefficient of the small grains. During the July period in 1914 (Table XIII) the transpiration per square meter per hour during midday ranged from 61 gm. for Siberian millet to 175 gm. for Galgalos wheat. The millets were just heading at this time, and oats, barley, and rye had begun to ripen, although the transpiration coefficient was still apparently near the maximum.

The loss of water from the plant surfaces during this period was 5 to 14 per cent of that from a water surface of equal area. In 1915 the plant surfaces lost relatively more, ranging from 10 to 25 per cent of that from a free water surface of the same area (Table XV).

It should be noted in this connection that the evaporation measurements were made in the open, while the transpiration measurements for the most part were made within the screened inclosure. The data just given regarding the transpiration of the plants relative to an equal free water surface are consequently somewhat too low.

During the August period in 1914 the transpiration measurements for alfalfa and Sudan grass were made both inside and outside the screened inclosure (Table XIV). The hourly transpiration of Sudan grass in the open was 11 per cent and that of alfalfa 29 per cent of the evaporation loss from a water surface of equal area as compared with a loss within the inclosure of 7 and 13 per cent, respectively.

The transpiration of the different plants per unit area of plant surface shows less variation than the transpiration per unit weight of dry matter produced. In other words, the greater efficiency exercised by some plants in the use of water appears to be due more to a reduction in plant surface than to a reduction of transpiration per unit area of surface. The latter effect is, however, in evidence, the plants characterized by a low-water requirement usually showing a somewhat lower transpiration rate per unit area.[1]

The determination of the surface area of a large plant from measurements on a few shoots or branches is necessarily only an approximation. For different sets of plants of the same crop the results were in satisfactory agreement. Thus, measurements of six sets of Kubanka wheat gave 49, 48, 47, 44, 52, and 49 sq. cm. of surface per gram (dry weight). The measurements were less accurate in the case of plants which branch freely, such as alfalfa. The greatest uncertainty, however, appears to be in the assumption that the various surfaces presented by a plant have the same transpiration loss per unit area.

COMPARISON OF THE ENERGY RECEIVED BY DIRECT RADIATION WITH THE ENERGY DISSIPATED BY TRANSPIRATION

If the area of the shadow thrown by a plant on a plane normal to the sun's rays is known, the direct solar radiation received by the plant in one hour, expressed in gram-calories, is equal to the product of the area of the shadow in square centimeters and the direct radiation energy in calories per square centimeter per hour.

The energy dissipated by the plant through transpiration during the same period is equal to the product of the transpiration in grams and the latent heat of vaporization (536 gm.-cal. per gram). The ratio of these two quantities represents the part played by direct sunlight in transpiration, assuming that all the radiation is absorbed. Such computations have been made for a number of plants employed in the transpiration measurements of 1914, and are presented in Table XVII. The measurements are based on the hourly transpiration and hourly radiation values at midday. For plants grown in the inclosure the radiation values have been corrected for the shade of the wire screen.

[1] The high value obtained for sorghum is due to the fact that the lower leaves were harvested early to prevent loss and were not included in the area measurements made at the time the plants were cut. These lower leaves were active during the transpiration period considered, so that the transpiring area was greater than that finally measured. The transpiration recorded per unit area is therefore too high.

TABLE XVII.—*A comparison of the energy received by direct radiation with the energy dissipated by transpiration during midday*

Period and crop.	Hourly transpiration.	Radiation (cal. per sq. cm. per hour in shelter).	Cross section of plant normal to sun's rays (area of plant shadow).	Ratio of radiation energy received to energy dissipated through transpiration.
July 7–16, 1914.	*Gm.*		*Sq. cm.*	
Wheat, Kubanka	400	58	2,000	0.54
Wheat, Galgalos	469	58	1,920	.44
Oat, Swedish Select	434	58	2,040	.51
Oat, Burt	405	58	1,940	.55
Barley	220	58	1,480	.73
Millet, Kursk	239	58	1,920	.87
Millet, Siberian	257	58	1,980	.83
Cowpea	317	58	2,230	.76
Aug. 2–11, 1914.				
Alfalfa, Grimm, E23–20–52	283	64	1,840	.78
Alfalfa, Grimm, E23	332	64	2,230	.80
Alfalfa, Grimm, E23 (in open)	326	80	2,200	1.01
Alfalfa, Grimm, 162–98A	529	64	2,870	.65

The area of the plant shadow in the case of the grain crops has been determined by considering the plants in a pot to have the form of a right cylinder, the diameter and height of which were determined from direct measurements and from photographs. The method of computing this area is readily seen from figure 4. Let x be the angle made by the sun's rays with the vertical at midday (zenith distance). The projection of the right cylinder of height h and diameter d on a plane normal to the sun's rays would give a rectangular figure with elliptical ends whose total length is $d \cos x + h \sin x$. In this expression $\frac{d}{2} \cos x$ represents the minor semidiameter of each elliptical portion, whose major semidiameter is $\frac{d}{2}$. The area of the elliptical portion is consequently $\frac{\pi}{4} d^2 \cos x$, while the area of the rectangular part of the figure is $h\, d \sin x$. The total area (a) is therefore—

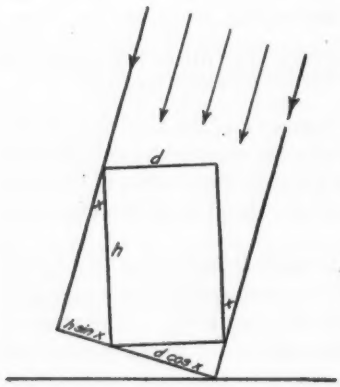


FIG. 4.—Determination of the area, on a plane normal to the sun's rays, of the shadow of a cylinder of diameter d and height h in terms of the angular departure (x) of the sun from the vertical.

$$a = \frac{\pi}{4} d^2 \cos x + h\, d \sin x.$$

The shadow areas of the other crops were computed from the projection of the geometrical figures which they most closely approximated, such as cylinders, spheres, or inverted truncated cones.

While measurements of this kind are at best approximations, the results given in Table XVII are consistent in showing that the energy received directly from the sun is insufficient to account for the energy dissipated by the plants through transpiration during the midday hours. Only in the case of alfalfa in the open is the direct solar radiation intercepted by the plant sufficient to account for the observed transpiration. Even on bright days, therefore, other sources of energy, such as the indirect radiation from the sky and from surrounding objects and the heat energy received directly from the air, contribute materially to the energy dissipated through transpiration. Comparative transpiration measurements of shaded and unshaded plants also show that the energy consumed in transpiration is only partially attributable to direct radiation.

RELATION OF TRANSPIRATION TO THE WEATHER

If transpiration is determined absolutely by the intensity of any one of the weather factors, the ratio of the daily transpiration to the daily intensity of this factor should give a regular graph when plotted. This graph, if the correlation were perfect, would be an expression of the relative transpiration coefficient of the plant considered.

In figure 5 are plotted the ratios of the daily transpiration of Kubanka wheat to the daily evaporation from the shallow tank. This graph shows a gradual increase in the transpiration coefficient to a maximum on July 13, followed by a somewhat more rapid decrease to harvest. While the graph shows many irregularities a similar response in transpiration and evaporation to changes in weather is indicated.

The second graph shows the ratio of transpiration to wet-bulb depression. Outstanding points in this graph indicate, of course, that on certain days the transpiration values were influenced by some factor other than the dryness of the air. Reference to the radiation graph will show that on such days the transpiration-radiation ratio is normal or shows a departure in the opposite sense to the ratio of transpiration to wet-bulb depression. In other words, both factors enter into the determination of the transpiration.

Similar departures are in evidence in the transpiration-temperature graph, and it will be noted that such departures are usually in an opposite sense to one or the other of the graphs just discussed. Temperature, therefore, also enters into the determination of the transpiration.

The ratio of transpiration to wind velocity is plotted at the bottom of figure 5. The change in the transpiration coefficient is evident in this graph, but no marked correlation is indicated.

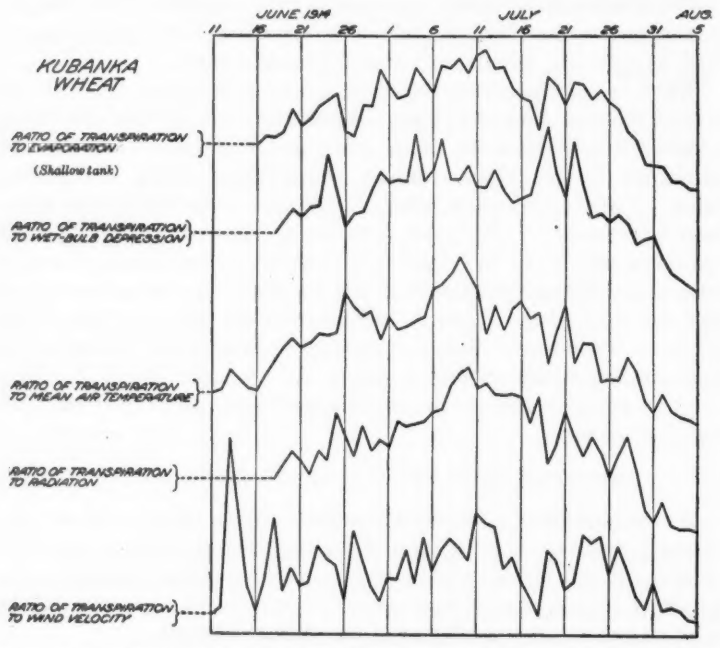

JUNE 1914
JULY
AUG.
11 16 21 26 1 6 11 16 21 26 31 5
KUBANKA WHEAT
RATIO OF TRANSPIRATION TO EVAPORATION (Shallow tank)
RATIO OF TRANSPIRATION TO WET-BULB DEPRESSION
RATIO OF TRANSPIRATION TO MEAN AIR TEMPERATURE
RATIO OF TRANSPIRATION TO RADIATION
RATIO OF TRANSPIRATION TO WIND VELOCITY

FIG. 5.—Ratios of the daily transpiration of Kubanka wheat to the daily intensity of various weather factors, plotted with approximately the same amplitude.

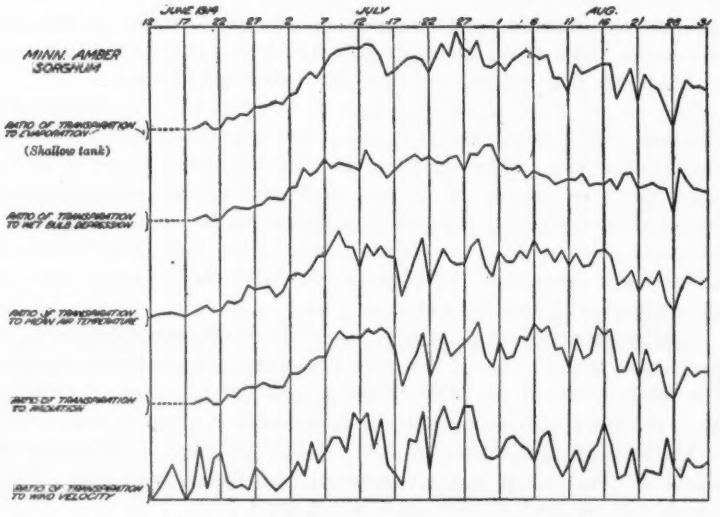

JUNE 1914
JULY
AUG.
MINN. AMBER SORGHUM
RATIO OF TRANSPIRATION TO EVAPORATION (Shallow tank)
RATIO OF TRANSPIRATION TO WET BULB DEPRESSION
RATIO OF TRANSPIRATION TO MEAN AIR TEMPERATURE
RATIO OF TRANSPIRATION TO RADIATION
RATIO OF TRANSPIRATION TO WIND VELOCITY

FIG. 6.—Ratios of the daily transpiration of Minnesota Amber sorghum to the daily intensity of various weather factors, plotted with approximately the same amplitude.

An inspection of the ratio graphs of sorghum and alfalfa (figs. 6 and 7) shows, as in the case of Kubanka wheat, a dependence of transpiration upon radiation, wet-bulb depression, and temperature. A marked departure in any one of the ratio graphs is usually, though not always, accompanied by a departure in the opposite sense in one of the other graphs. The correlation of transpiration with wind velocity is low in the case of both of these crops.

MARCH OF TRANSPIRATION DURING THE GROWTH PERIOD AS SHOWN BY THE RATIO OF DAILY TRANSPIRATION TO DAILY EVAPORATION

Although the association of transpiration with wet-bulb depression is fully as marked as the transpiration-evaporation association (see correlation coefficients, p. 204), the writers have decided to employ the latter ratio to represent the change in the transpiration coefficient of the different plants, since it is already used extensively.[1]

The ratios of the daily transpiration of each crop to the daily evaporation (shallow tank) are plotted as percentages of the maximum in figures 8 and 9. By this method different crops may be easily compared.

The graphs show irregularities due to the lack of an exact correlation between evaporation and transpiration, or to errors in the measurements. On days when rain occurred the outstanding points are probably due to inaccurate determinations of the transpiration.[2] The outstanding ratios on days without rain are not explainable on this basis and are to be regarded as expressions of the inexact correlation of transpiration and evaporation as here measured.

The general trend of the graphs indicates a gradual increase in the transpiration coefficient from seedtime to a maximum which in the case of annual plants comes just before they begin to ripen.

MEASUREMENTS IN 1914

In 1914 (fig. 8) the small grains were well advanced before the transpiration measurements were begun. They did not reach their maximum transpiration rate, however, until about one month later.

[1] Livingston, B. E. The relation of desert plants to soil moisture and to evaporation. 78 p., illus. Washington, D. C., 1906 (Carnegie Inst. Washington Pub. 50.) Literature cited, p. 77–78.

——— The resistance offered by leaves to transpirational water loss. *In* Plant World, v. 16, no. 1, p. 1–35, illus. 1913.

[2] Even a small amount of rain wets the plant thoroughly, a part of the water remaining on the surface of the plants and a part being absorbed by the dry or living leaves or caught in the leaf sheaths or flower heads. Water is also held on the surface of the pot and a small amount may find its way into the pot by suction due to the change in temperature. If the morning weighing following a rain during the night is taken as the basis of determining the transportation, on the subsequent day the transpiration is too high since some of the water is merely evaporated from the surface of the plant and pot. If the two days are combined and morning weighing discarded, the transpiration is too low since transpiration from wet plants is lower than from dry plants, and since an equivalent of the water which was absorbed must be transpired before a loss in weight can be recorded. Notwithstanding the errors of the second method, it seems best not to introduce the greater uncertainty involved in the first method and to regard the outstanding determinations on rainy days as experimental errors which can not at present be successfully overcome without actually protecting the plants from rain, which would change the conditions under which field crops are grown.

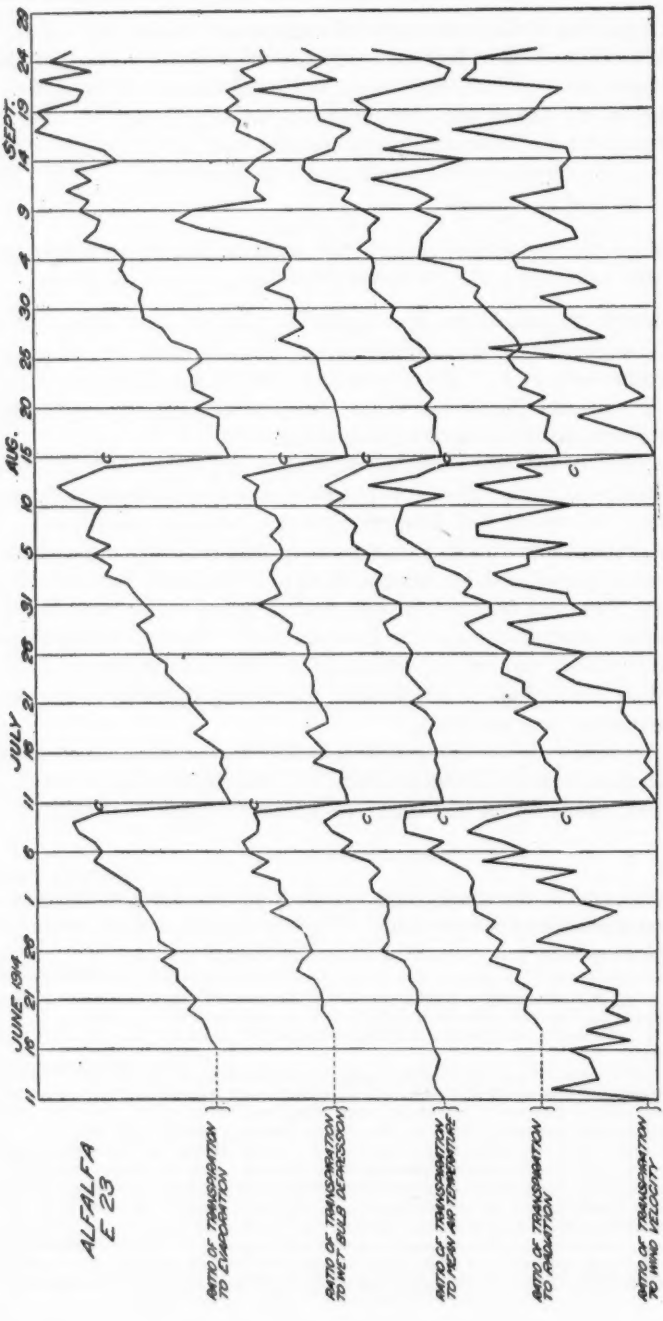


FIG. 7.—Ratios of the daily transpiration of alfalfa, E-23, to the daily intensity of various weather factors, plotted with approximately the same amplitude. *C* indicates the date of cutting.

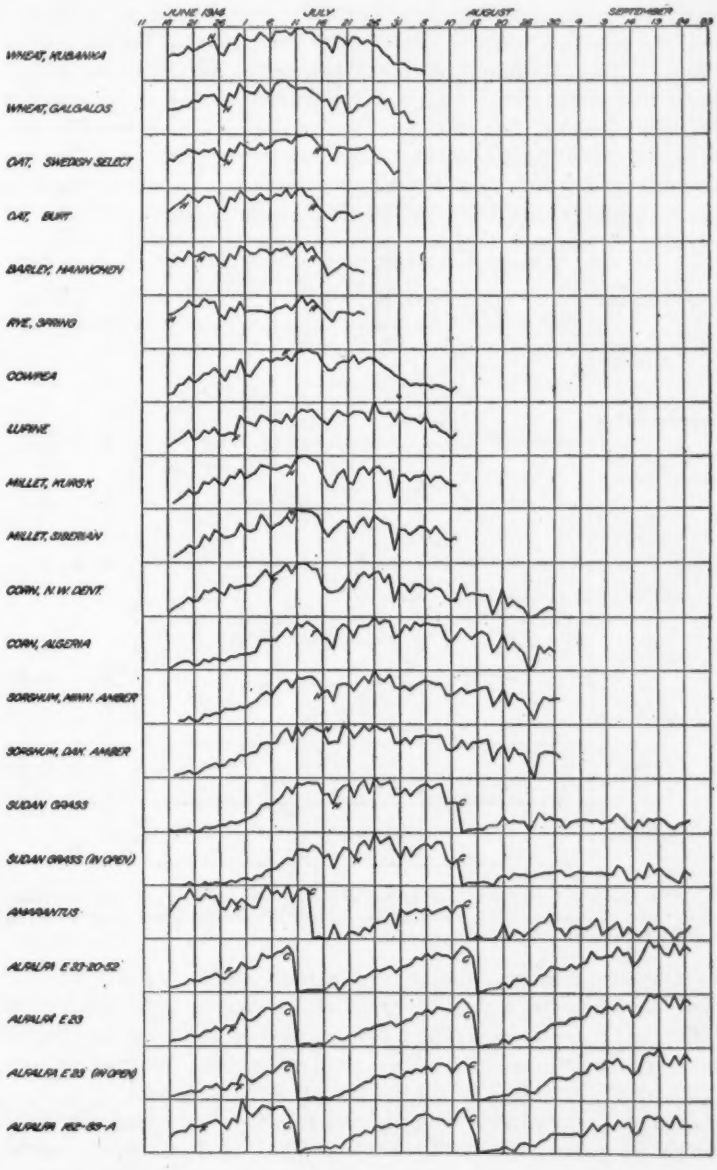


FIG. 8.—The ratio of daily transpiration of different crops in 1914 to daily evaporation (shallow tank) plotted in percentage of the maximum. The letter *C* in the graph indicates date of cutting, followed by a new growth from the established root system. *H* signifies heading; *F*, flowering; *R*, ripening; and *T*, tasseling.

The transpiration coefficient of Kubanka wheat had reached half the maximum value when the daily weighings were begun, although the total transpiration from seedtime to this date was only 10 per cent of that for the whole season. A gradual increase in the transpiration coefficient is recorded from June 16 to a maximum on July 12. Although the plants began to head on June 15, this produced no marked change in the transpiration coefficient. The drop in the graph following the period of heading is not significant in this connection since a similar drop was recorded for the other crops, and it is evidently due to the failure of

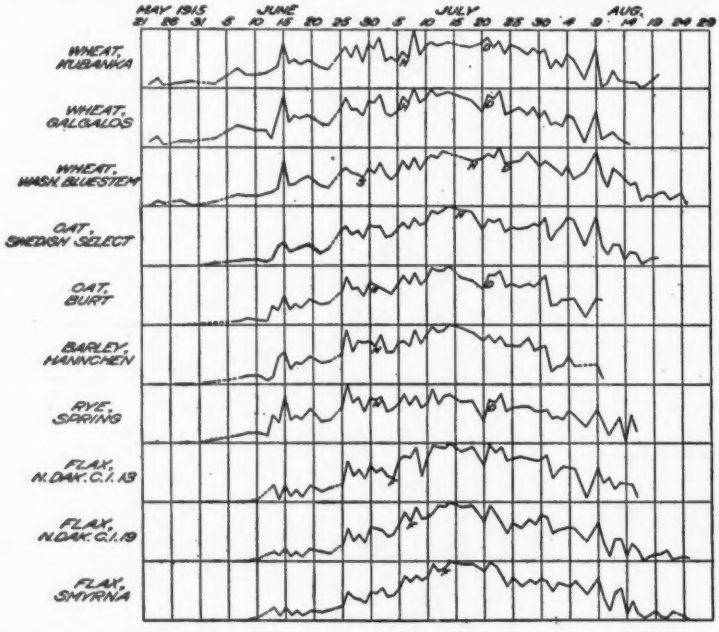


FIG. 9.—The ratio of daily transpiration of different crops grown in 1915 to daily evaporation (shallow tank) plotted in percentage of the maximum. *S* signifies that the plants were forming shoots; *H*, heading; *F*, flowering; and *D*, lower leaves dying.

evaporation and transpiration to respond proportionately to the weather conditions on these days. The gradual decrease in the transpiration coefficient following the maximum is indicated by the graph and begins almost one month before harvest. At harvest time the transpiration coefficient of Kubanka was still 20 per cent of the maximum.

Galgalos wheat which began to head two days later than Kubanka reached its maximum four days earlier. The period of gradual decline was approximately one month long and the transpiration coefficient at harvest was 20 per cent of the maximum. The depression in the curve in the early part of the period of decline is probably not significant since

it is recorded for all crops and is to be attributed largely to the errors in measuring transpiration during a period of rainy weather.

The transpiration coefficient of Swedish Select oat, which began to head on June 28, did not reach its maximum until July 13, after which it declined rather rapidly to about 25 per cent of the maximum at harvest time. Burt oat began to head much earlier, but showed the same gradual increase to the maximum. The value at harvest time was very high, amounting to 50 per cent of the maximum. Hannchen barley and Burt oat showed very little difference in the march of the transpiration coefficient.

Rye was beginning to head when the measurements were started. The transpiration coefficient was unusually uniform throughout the season. At harvest it was 65 per cent of the maximum and did not differ materially from that at the period of heading.

The graph for cowpea is almost symmetrical, beginning and ending at about 20 per cent of the maximum, which occurred just after the flowering period.

Lupine blossomed earlier than cowpea and showed no marked maximum period, the rate remaining about the same from the 10th of July to the 1st of August.

Kursk and Siberian millet showed no significant differences. The graphs include practically the whole growth period. The increase was rapid and uniform and the maximum was reached at the period of heading. The transpiration coefficient was about 40 per cent of the maximum at the time of harvest.

The two varieties of Amber sorghum showed no marked differences. Dakota Amber headed a little earlier than Minnesota Amber. The maximum transpiration coefficient of both crops occurred about 10 days after the plants began to head. The decline was gradual, the value at harvest being over 40 per cent of the maximum, notwithstanding the fact that the seeds were ripe at that time.

Sudan grass was grown in the screened inclosure and also in the open. The transpiration coefficient of the plants in the inclosure increased somewhat more rapidly at first than in the open, although the maximum was reached at the same time. The second crop was much smaller than the first and the transpiration coefficient reached only about one-fourth the value attained during the first crop.

Algeria corn reached its maximum much later than Northwestern Dent and showed no marked decrease in its transpiration coefficient, the value at harvest being 40 per cent of the maximum. Algeria corn did not ripen at Akron, which accounts for the high transpiration coefficient when the crop was harvested.

The graph for Amaranthus shows no marked change in the transpiration coefficient during the first crop. In other words, the young large-

leaved plants lost water almost as rapidly as the older plants on which the lower leaves either drop off or become relatively inactive.

Four sets of alfalfa were included in these measurements. Three of these sets were grown from seed, while the fourth alfalfa, 162–98A, was grown from cuttings. The transpiration coefficient of the latter was already 25 per cent of the maximum when the measurements were begun. Some of the plants in the first crop began to bloom when the transpiration coefficient was only 40 per cent of the maximum. In the second and third crops the plants were harvested shortly after they had developed flowers. The march of the transpiration coefficient for each variety was approximately the same, with the exception of the first crop of alfalfa, 163–98A, which developed much more rapidly than the other varieties. The set in the open developed more slowly than in the inclosure.

The relative loss of water at different periods in the growth of a crop, the evaporation rate being uniform, can readily be determined from the graphs representing the transpiration–evaporation ratio. The weekly loss from different crops expressed in percentages of the total is given in Table XVIII.

TABLE XVIII.—*Weekly transpiration under uniform conditions of evaporation expressed in terms of percentage of the total, 1914*

Crop.	Week of growth.										
	1st.	2d.	3d.	4th.	5th.	6th.	7th.	8th.	9th.	10th.	11th.
Northwestern Dent corn		2	4	10	13	12	14	14	13	11	7
Algeria corn		2	4	8	13	12	14	15	13	11	8
Sorghum, Minnesota Amber		2	5	11	14	12	15	13	11	10	7
Sorghum, Dakota Amber		2	5	10	14	14	15	12	11	10	7
Sudan grass (first crop)		1	2	8	17	17	18	19	16	.....	.....
Sudan grass (first crop in open)		1	1	6	17	17	20	20	18	.....	.....
Alfalfa, E23–20–52 (second crop)	2	10	22	30	36	.....	.....	.....	.....	.....	.....
Alfalfa, E23 (second crop)	3	10	21	30	36	.....	.....	.....	.....	.....	.....
Alfalfa, E23 (second crop in open)	2	11	23	32	32	.....	.....	.....	.....	.....	.....
Alfalfa, 162–98A (second crop)	4	13	23	30	30	.....	.....	.....	.....	.....	.....

The loss from corn and sorghum during the week preceding the measurements was very slight, amounting to less than 1 per cent of the total. The mean transpiration of the four crops for the second and succeeding weeks was 2, 5, 10, 14, 13, 15, 14, 12, 11, and 7 per cent of the total. The drop in the sixth week is not significant and is probably due to imperfect measurements of transpiration during days when rain occurred.

Sudan grass in its early stages of growth developed more rapidly in the inclosure than in the open. Alfalfa produced its second crop in a period of five weeks, two-thirds of the total transpiration occurring during the last two weeks of the growth period. The transpiration coefficient changed very rapidly, being approximately one-third the maximum in the second week and two-thirds the maximum in the third week.

MEASUREMENTS IN 1915

The daily weighings in 1915 were begun as soon as the plants had started to grow, and the total transpiration period of wheat, oats, barley, rye, and flax is included in the transpiration-evaporation graphs presented in figure 9. These graphs show the march in the transpiration independently of the fluctuations due to daily changes in the weather, assuming the latter to be represented by the fluctuations in evaporation. On the same assumption, the march of the weekly transpiration under uniform weather conditions is expressed numerically in Table XIX in per cent of the total transpiration.

TABLE XIX.—*Weekly transpiration under uniform conditions of evaporation expressed in terms of percentage of the total, 1915*

Crop.	Week of growth.												
	1st.	2d.	3d.	4th.	5th.	6th.	7th.	8th.	9th.	10th.	11th.	12th.	13th.
Wheat, Kubanka 1440	1	2	4	8	9	12	12	13	13	7	8	4	2
Wheat, Galgalos	2	3	5	8	9	11	13	15	12	10	8	4	.....
Wheat, Washington Bluestem	1	1	3	6	7	9	11	14	14	12	10	9	4
Oat, Swedish Select	1	2	6	8	11	14	18	13	11	11	5	.....	.....
Oat, Burt	0	3	7	10	12	16	19	14	12	7	.....	.....	.....
Barley, Hannchen	1	2	8	10	14	16	18	15	10	6	.....	.....	.....
Rye, spring	1	4	8	11	12	13	14	12	10	8	7	.....	.....
Flax, North Dakota (C. I. 13)	2	4	8	10	17	17	16	13	8	5	.....	.....	.....
Flax, North Dakota (C. I. 19)	2	3	6	10	18	18	14	13	10	4	2	.....	.....
Flax, Smyrna	2	3	6	9	15	19	15	12	12	5	2	.....	.....

The wheats reached their maximum transpiration in the eighth week following emergence and were harvested in the twelfth or thirteenth week. Oats, barley, and rye, which were planted a little later, reached their maximum in the seventh week of growth and were harvested in the tenth or eleventh week. The flax varieties reached their maximum in the sixth week, although they were not harvested until five weeks later.

THE TRANSPIRATION COEFFICIENT DURING THE EARLY PERIODS OF GROWTH

The transpiration-evaporation graphs during the early development of the crops either approximate a straight line, or curve upward as in the case of Sudan grass. The latter form suggests an exponential relationship, which would mean that the rate of increase in the transpiration coefficient is proportional to the transpiration coefficient itself.

Let T represent the transpiration, E the evaporation, and $\frac{T}{E}=k$ the transpiration coefficient (referred to evaporation) at the time t in the development of the crop. If the rate of increase of the transpiration coefficient $\frac{dk}{dt}$ is proportional to the transpiration coefficient, then

$$\frac{dk}{dt}=a'k \qquad (1)$$

in which a' is a constant of proportionality.

Integrating equation (1) and transforming to common logarithms, we have

$$\log_{10} k = at + c \tag{2}$$

in which c is the logarithm of k when $t = o$—that is, at the beginning of the period under discussion. Expressing (2) exponentially, we have

$$k = 10^{at+c} = k_0 . 10^{at} \tag{3}$$

Therefore if the logarithms of the daily transpiration when plotted against the time form a straight line, the condition expressed in equation (2) is satisfied, and the transpiration coefficient increases in accordance with the assumption made above.

The accompanying graphs (fig. 10 to 15) show that an approximate linear relationship does exist between the logarithm of the transpiration coefficient and the time in the case of corn, sorghum, Sudan grass,

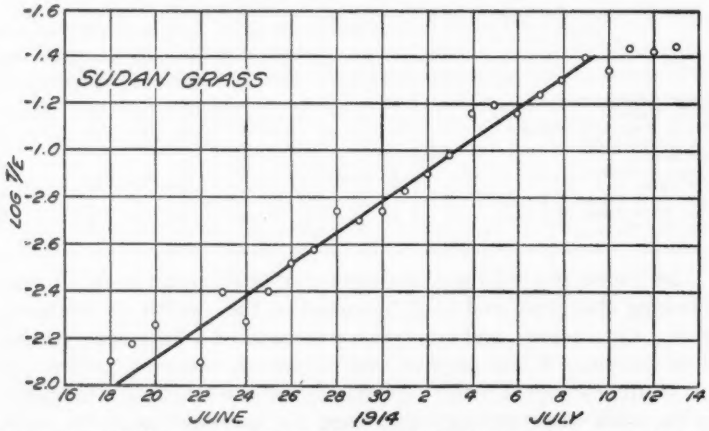


FIG. 10.—Graph showing a linear relation between the logarithm of the transpiration-evaporation ratio of Sudan grass and the time.

and alfalfa. The transpiration coefficient of these plants during the early stages of growth therefore changes exponentially.

The numerical value of the coefficient a may now be computed. This is represented by the slope of the graphs in figures 10 to 15 and from equation (2) it follows that

$$a = \frac{\log k_t - \log k_o}{t} \tag{4}$$

The significance of a can be readily seen by a comparison of equation (3) with the compound interest law

$$k = k_o \left(1 + \frac{r}{100}\right) t,$$

from which it is evident that

$$10^a = 1 + \frac{r}{100}, \text{ or}$$

$$a = \log_{10}\left(1 + \frac{r}{100}\right),$$

in which $\frac{r}{100}$ is the interest rate. From this relationship the daily rate of increase (daily interest) can be readily determined.

The rate of increase may also be expressed in terms of the time required for k to double in value.

Let k_1 be the value of k at the time t_1. If $k = 2k_1$,

$$\frac{k}{k_1} = \frac{10^{at}}{10^{at_1}} = 10^{a(t - t_1)} = 2,$$

$$a(t - t_1) = \log_{10} 2 = 0.3010,$$

$$t - t_1 = \frac{0.3010}{a}$$

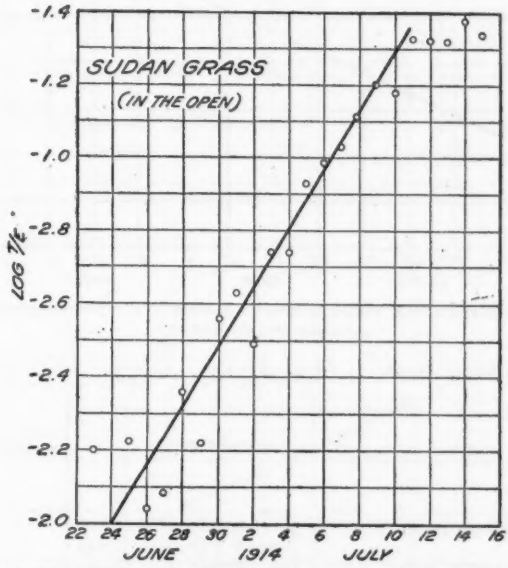


FIG. 11.—Graph showing a linear relation between the logarithm of the transpiration-evaporation ratio of Sudan grass (grown in the open) and the time.

The values of the coefficient a, the rate of increase r, and the time $(t - t_1)$ required for k to double in value are given in Table XX for the various crops considered in figures 10 to 15.

It will be seen from Table XX that the daily increase in the transpiration coefficient of Sudan grass during the early stages of growth was extremely rapid, ranging from 16 to 21 per cent. Since this is compounded daily, four days are required for the transpiration coefficient to double in value during this active growth period. The growth rate during the early stages of Algeria corn and sorghum was less rapid, about seven days being required for k to double in value.

The results obtained in case of alfalfa are of special interest, for the plants were much more advanced than those just considered. In fact, in two of the three alfalfa measurements given the periods were terminated by the harvesting of the plants while in full bloom. The data show that during the periods considered the transpiration coefficient of alfalfa was compounding at the rate of 8 to 9 per cent per day, thus doubling in value every 8 or 9 days.

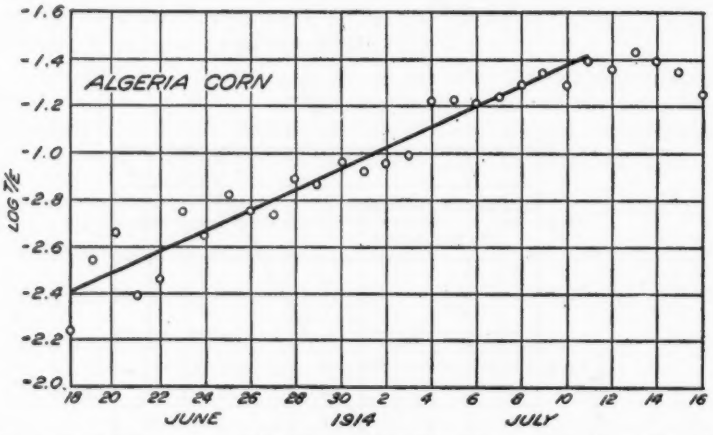


FIG. 12.—Graph showing a linear relation between the logarithm of the transpiration-evaporation ratio of Algeria corn and the time.

TABLE XX.—*Rate of increase in the transpiration coefficient of different crops in 1914*

Crop.	Observation period.	(a)	Daily rate of increase.	Days required for k to double in value.
			Per cent.	
Corn, Northwestern Dent	June 18–July 9	0.026	6.2	11.6
Corn, Algeria	June 18–July 11	.044	10.7	6.8
Sorghum, Minnesota Amber	June 18–July 9	.041	9.9	7.3
Sudan grass (in inclosure)	June 18–July 10	.066	16.4	4.6
Sudan grass (in open)	June 24–July 11	.082	20.8	3.7
Alfalfa, E23 (first crop in open)	June 16–July 10	.033	7.9	9.1
Alfalfa, E23–20–52 (first crop)	June 19–July 9	.037	8.9	8.1
Alfalfa, E23–20–52 (second crop)	July 18–Aug. 5	.037	8.9	8.1

A test of the validity of the computations may be obtained by comparing the observed graph of the transpiration coefficient with that computed from equation (3). The result of such a computation in the case of Sudan grass (in the open) is given in figure 16, the computed graph being represented by the smooth curve, while the observed values are represented by circles.

RELATIVE DAILY TRANSPIRATION OF DIFFERENT CROPS

In the preceding discussion the transpiration-evaporation ratio has been used in order to eliminate, so far as possible, the daily fluctuations

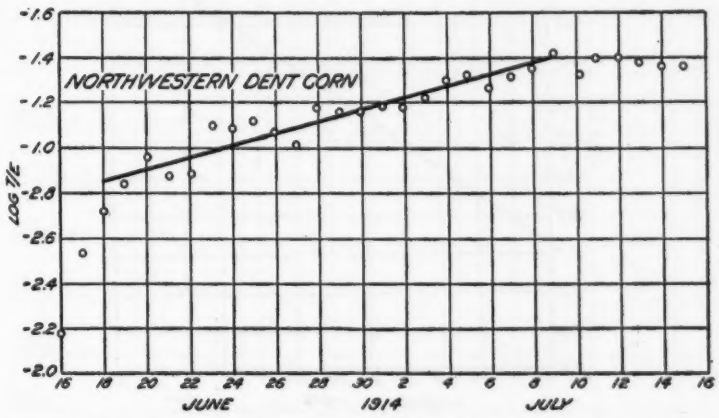


FIG. 13.—Graph showing a linear relation between the logarithm of the transpiration-evaporation ratio of Northwestern Dent corn and the time.

in transpiration due to changes in weather. The relative march of the transpiration of any two crops can, however, be determined directly

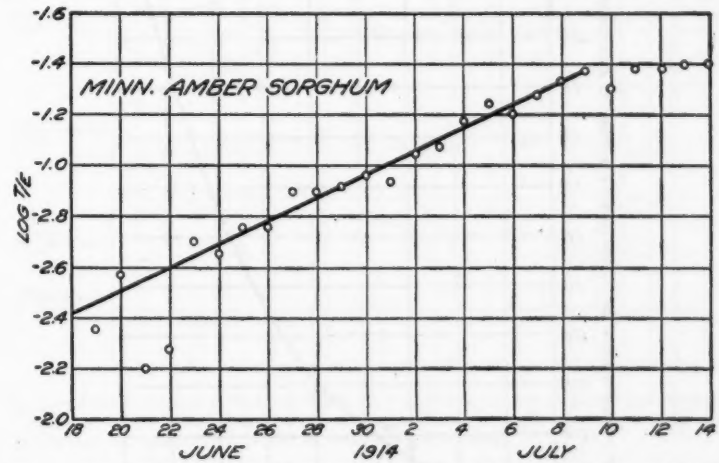


FIG. 14.—Graph showing a linear relation between the logarithm of the transpiration-evaporation ratio of Minnesota Amber sorghum and the time.

by comparing the transpiration day by day; in other words, if two crops are grown simultaneously and have approximately the same length of growing season, the relative change in transpiration may be obtained by

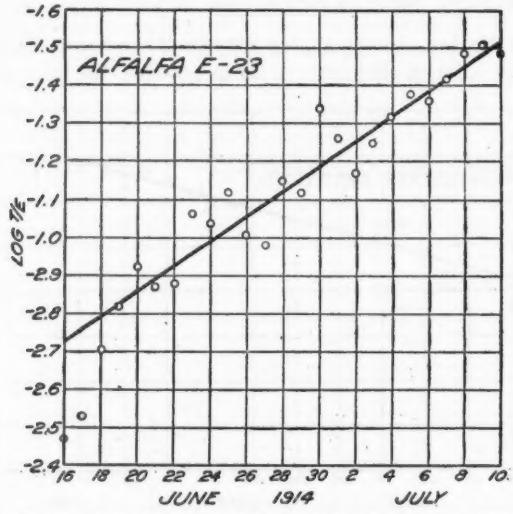


FIG. 15.—Graph showing a linear relation between the logarithm of the transpiration-evaporation ratio of Alfalfa E–23 (in the open) and the time.

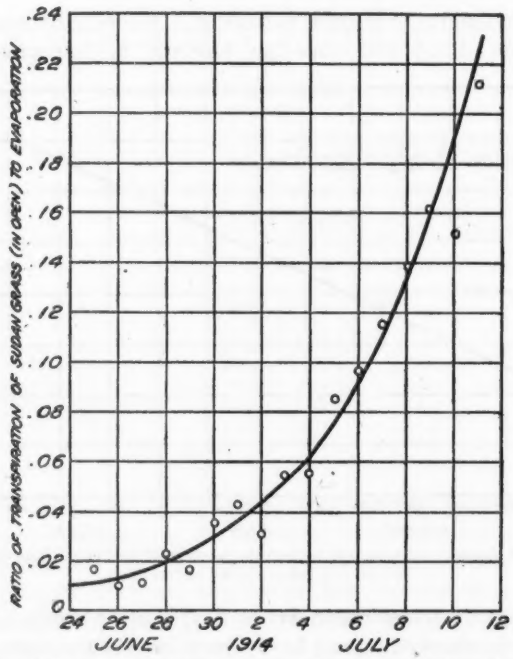


FIG. 16.—Observed daily ratios of transpiration to evaporation during early stages of growth of Sudan grass (shown by circles) compared with exponential graph computed from the relationship shown in figure 11 (solid line).

plotting the ratio of the daily transpiration of one crop to that of the other.

If such ratios depart from unity to any great extent, the difference between the departure of the ratio and that of its reciprocal is so great that the graphs resulting from the plotting of such ratios are not readily com-

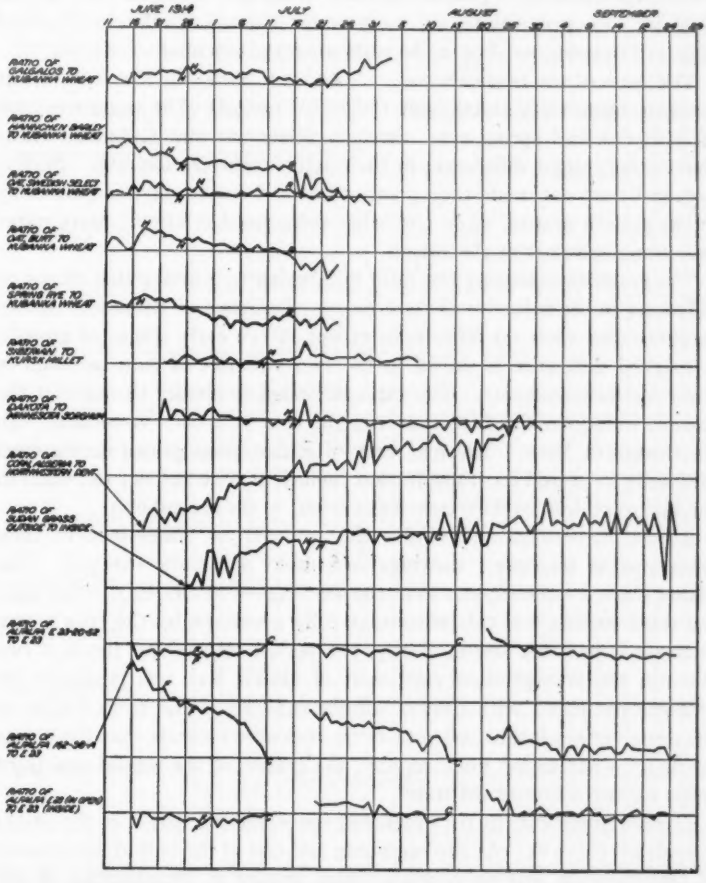


FIG. 17.—Graphs of the daily ratios of the transpiration of the different crops grown in 1914 plotted logarithmically. *F* signifies flowering; *C* indicates the cutting of the crop, which was followed by a new growth from the established root system; *H*, heading; and *R*, ripening.

parable. By plotting the logarithm of the ratio, however, the same departure is obtained for a ratio and its reciprocal. The transpiration ratios of a number of different crops grown in 1914 are shown in figure 17, plotted logarithmically.

The first graph represents the ratio of the daily transpiration of Galgalos wheat to the daily transpiration of Kubanka wheat. The early

ratios are irregular, owing to rainy weather and to the small size of the plants. After this period no difference in the transpiration of the two crops was observable until after July 10, at which time the plants began to show signs of ripening through the dying back of the lower leaves. There was then a sudden drop in the relative transpiration, followed after about two weeks by a gradual increase to harvest time; in other words, Galgalos lost proportionately more water than Kubanka in the final stages of ripening but less in the early stages of ripening.

The ratio of the transpiration of Hannchen barley to Kubanka wheat decreased gradually throughout the whole period. The same was true of Burt oat and spring rye. Swedish Select oat and Kubanka wheat showed only slight differences in the relative transpiration rate. Barley, rye, and Burt oat made their greatest demand on the soil moisture early in the growth season, while the other crops used relatively more water near the latter part of the season.

The graph representing the ratio of Siberian to Kursk millet shows no difference in the behavior of these crops. Dakota and Minnesota Amber sorghum also show no differences except in the early stages of growth. A marked difference is shown in the two varieties of corn included in the 1914 measurements. The ratio increased gradually throughout the season, owing to the fact that Algeria is a late corn compared with Northwestern Dent. The first crop of Sudan grass grown in the open gradually increased its transpiration coefficient with respect to Sudan in the inclosure, but no difference was evident in the second crop.

Alfalfa E23–20–52 and alfalfa E23 showed no differences in their transpiration response. Cuttings were used in alfalfa 162–98A. The plants started more rapidly than the seedlings of alfalfa E23. Not until the third cutting was this advantage fully overcome by the crop grown from seed; in other words, during the period covered by the first two cuttings the transpiration coefficient of alfalfa E23 was gradually increasing compared with that of alfalfa 162–98A. The ratio graphs of the same variety inside and outside the inclosure indicate that the plants inside grew somewhat more rapidly, the graphs of the second and third crops having a downward trend.

The measurements in 1915 included the whole life period of the plants considered (fig. 18). At the beginning and end of the period the amount of transpiration was very small, which results in irregularities in the ratios. The graph representing the ratio of Galgalos wheat to Kubanka wheat corresponds closely with that of 1914, although Kubanka transpired more rapidly than Galgalos in the ripening stages. In 1914 the graph indicates a relatively rapid loss from Galgalos at the end of the ripening season. Galgalos was rusted badly in 1915, and this may account for the comparatively rapid decline in transpiration rate just before harvest.

Two sets of Kubanka wheat were included in the 1915 measurements, which showed the same water requirement (405 ± 6 and 406 ± 3). The second set (pots 109 to 114) produced a heavier crop and was three days later in ripening, which accounts for the rise in the graph at the end of

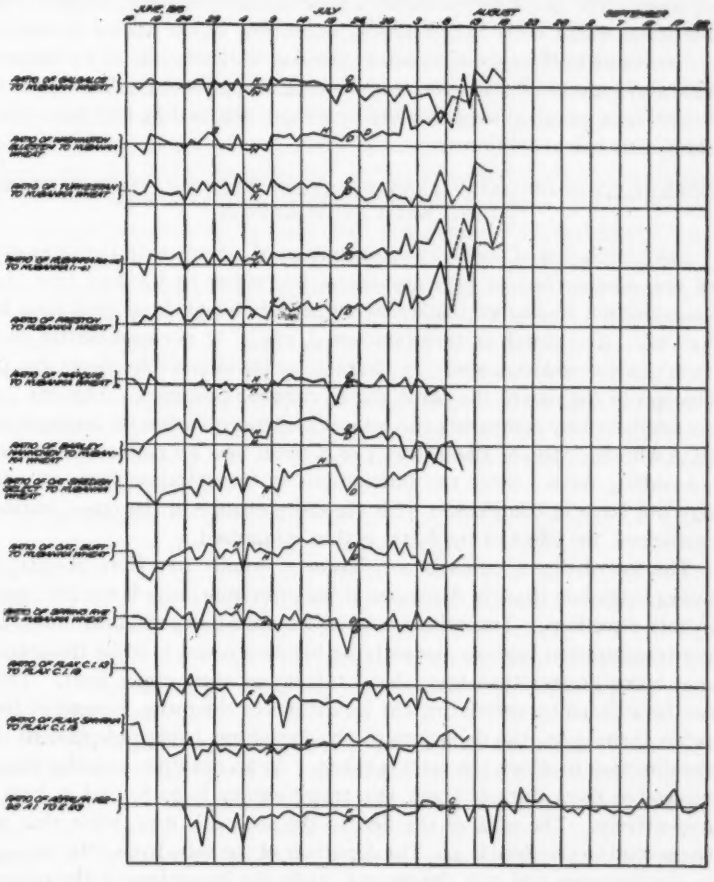


FIG. 18.—Graphs of the daily ratios of the transpiration of the different crops grown in 1915 plotted logarithmically. *H* signifies heading; *D*, lower leaves dying; *S*, that the plants were forming shoots; *F*, flowering; and *C*, the cutting of the crop, which was followed by a new growth from the established root system.

the season. The rise of the ratio graph is even more marked in Washington Bluestem and Preston, owing to the fact that they ripened five days later than Kubanka. Turkestan showed a relatively greater transpiration than Kubanka early in the season, while Marquis is nearly identical with Kubanka throughout.

Barley and Burt oat increased in transpiration more rapidly and ripened more rapidly than wheat. The ratio graph for Swedish Select oat shows a steady increase from seedtime to heading, when there is a marked drop, followed at first by a gradual and finally by a rapid rise as the wheat ripened. The graph for rye shows a relatively greater transpiration than Kubanka wheat early in the season, decreasing as the season advances.

No marked difference is shown in the flax varieties. C. I. 13 ripened nine days ahead of the other varieties. Except for a gradual increase in the ratio graph throughout the first crop, alfalfa E23 and 162–98A1 showed no marked differences.

CORRELATION OF DAILY TRANSPIRATION WITH WEATHER FACTORS AND WITH EVAPORATION

The correlation of the daily transpiration of a plant with the intensity of the weather factors presents difficulties, owing to the fact that the transpiration coefficient undergoes a gradual change from seed time to harvest. (See march of transpiration, p. 189.) It is consequently necessary in a correlation study to eliminate as far as possible effects due to changes in the size of the plant and to ripening processes. This can be accomplished by comparing the ratio of the transpiration on consecutive days with the ratio of the intensity of a given weather factor for the corresponding days. Since the fluctuations in transpiration from day to day are large in comparison with the daily change in the transpiration coefficient, the effect of the latter is thus minimized.

The use of direct ratios is not, however, wholly free from objection, owing to the fact that the departure of the ratio from unity is not the same in both directions. Transpiration ratios less than unity will be confined in the transpiration table to classes lying between 0 and 1, while transpiration ratios greater than unity have infinity as their upper limit. This can be avoided by correlating the logarithms of the ratios, instead of the ratios themselves, the departure of the logarithm being independent of the direction in which the ratio is taken. As an example, consider three successive days during which the transpiration is 2, 8, and 2 kgm., respectively. The ratio of the first to the second is 0.25, while that of the second to the third is 4. The departure of the ratio from unity is 0.75 in the first case and 3 in the second, while the logarithms of the ratios, -1.3979 (that is, -0.6021) and 0.6021, respectively, show the same departure from zero.

Since it was not practicable to determine the daily transpiration with an accuracy greater than 0.1 kgm., the uncertainty of the ratio of the transpiration on consecutive days increases as the daily transpiration decreases. For this reason only pairs of terms in which at least one of the pair showed a transpiration of 0.6 kgm. or more have been used in the correlation tables.

In all cases where the available transpiration measurements were sufficiently numerous to justify the procedure, the correlation has been

determined between the daily transpiration of each crop and the radiation, temperature, wet-bulb depression, wind velocity, and evaporation from the shallow and from the deep tanks, making 6 correlation tables for a crop, or about 200 tables in all. In order to avoid in the correlation studies the error arising from the change in the transpiration coefficient as the crops develop, the writers have, as outlined above, compared the transpiration ratio on consecutive days with the ratio of the intensity of the weather factor on corresponding days. The difficulty arising from the asymmetry of these ratios has been avoided by taking the logarithm of the ratio in each case. This is, of course, equivalent to taking the difference of the logarithms of the two terms of the ratio, which was the procedure actually followed. In other words, the data in Tables I and III were first converted to a logarithmic basis, and the logarithmic differences then determined day by day. In brief, then, the actual correlation is between the logarithm of the transpiration ratio on consecutive days and the logarithm of the ratio of the intensity of the given weather factor on corresponding days. The transpiration of a crop on a given day thus normally enters twice into the correlation table for that crop, once as the numerator and once as the denominator of the ratios involving the transpiration on consecutive days. The results of the correlation studies are summarized in Tables XXI to XXIII, inclusive.

SMALL GRAINS.—The small grains in Table XXI show such similarity in the response of transpiration to various weather factors that the group may profitably be considered as a whole. The correlation coefficients are higher in 1914 than in 1915. It will be recalled that the latter season was cooler, more cloudy, and included many more rainy days. The correlation of transpiration with air temperature is usually, in 9 cases out of 12, slightly higher than with radiation, but the difference is usually less than its probable error.

The correlation coefficients of transpiration of the small grains with wet-bulb depression and with evaporation (shallow tank) show a striking agreement. Considered as a group, they are markedly higher than the correlations with either radiation or temperature, and constitute the highest correlations in the series. Their agreement appears to be due, in part at least, to the fact that the depression in the wet-bulb temperature is dependent upon the rate of evaporation from the muslin covering. It is of interest in this connection to recall the difference in exposure of the wet-bulb instrument and the shallow tank, the former being shaded from solar radiation, while the tank was blackened and fully exposed to the sun's rays.

The evaporation from the deep tank showed a lower correlation with transpiration than the shallow tank. The deep-tank evaporation is correlated with transpiration approximately to the same extent as radiation or temperature. In 1915 the correlation of the deep-tank evaporation with transpiration was markedly lower for many of the small grains.

TABLE XXI.—*Correlation of transpiration of small grains with intensity of weather factors and with evaporation*

Plant.	Year.	Radiation.	Temperature.	Wet-bulb depression.	Evaporation.		Wind.
					Shallow tank.	Deep tank.	
Wheat, Kubanka	1914	0.64±0.06	0.72±0.05	0.88±0.02	0.85±0.03	0.76±0.04	0.26±0.09
Do	1915	.57± .08	.66± .06	.77± .05	.73± .06	.55± .07	.26± .09
Wheat, Galgalos	1914	.63± .06	.73± .05	.86± .03	.86± .03	.70± .05	.29± .09
Do	1915	.55± .08	.64± .06	.85± .04	.81± .04	.67± .06	.25± .09
Oat, Swedish Select	1914	.66± .06	.69± .05	.86± .03	.85± .03	.78± .04	.17± .10
Do	1915	.62± .07	.55± .06	.67± .06	.74± .05	.47± .07	.21± .09
Oat, Burt	1914	.69± .06	.74± .05	.89± .02	.90± .02	.75± .05	.21± .10
Do	1915	.66± .07	.64± .06	.80± .05	.89± .03	.64± .06	.15± .10
Barley, Hannchen	1914	.61± .07	.66± .06	.85± .03	.86± .03	.72± .05	.19± .11
Do	1915	.49± .09	.63± .06	.71± .06	.71± .06	.49± .07	.13± .10
Rye, spring	1914	.65± .06	.73± .05	.94± .01	.91± .02	.77± .04	.19± .10
Do	1915	.65± .06	.55± .06	.73± .05	.79± .04	.47± .07	.15± .09
Mean of 1914 coefficients		.65	.71	.88	.87	.75	.22
Mean of all coefficients		.62	.66	.82	.82	.65	.21
Square of mean of 1914 coefficients		.42	.50	.77	.76	.56	.05
Square of mean of all coefficients		.38	.44	.67	.67	.42	.04

Wind velocity showed during both years a very low correlation with transpiration.

The relative influence of the various climatic factors on transpiration, as expressed by these correlations, may now be considered. If these factors are regarded as independent causative elements in transpiration, the dependence is shown by the square of the correlation coefficient. On this basis the transpiration of the small grains during the two seasons was determined by the different weather factors as follows: Radiation, 38 per cent; temperature, 44 per cent; wet-bulb depression, 67 per cent; wind, 4 per cent. The fact that the sum of these coefficients exceeds unity is the result of intercorrelation among the weather factors.

The association of the transpiration of the small grains with evaporation (shallow tank) is 67 per cent; or the same as with wet-bulb depression. The evaporation from the deep tank shows an association of 42 per cent with transpiration.

MILLET, CORN, AND SORGHUM.—The correlation of the transpiration of millet, corn, and sorghum with the several climatic factors is given in Table XXII. As in the case of the cereals, the coefficients are higher for 1914 than for 1915. The correlation coefficients of the transpiration of these crops with the intensity of the various weather factors show the same relationships disclosed in the case of the cereals. The highest correlation is obtained with wet-bulb depression and with the evaporation from the shallow tank. A somewhat lower correlation is obtained in the case of temperature, radiation, and evaporation (deep tank), which are correlated with transpiration nearly equally. Wind shows as before a very low correlation with transpiration.

TABLE XXII.—*Correlation of transpiration of millet, corn, sorghum, and Sudan grass with intensity of weather factors and with evaporation*

Plant.	Year.	Radiation.	Temperature.	Wet-bulb depression.	Evaporation.		Wind.
					Shallow tank.	Deep tank.	
Millet, Kursk	1914	0.54±0.07	0.61±0.06	0.77±0.04	0.68±0.05	0.66±0.05	0.23±0.09
Do	1915	.58± .07	.63± .06	.70± .05	.78± .04	.49± .08	.19± .10
Millet, Siberian	1914	.57± .06	.64± .06	.78± .04	.73± .04	.69± .05	.31± .08
Sorghum, Minnesota Amber	1914	.61± .05	.64± .05	.79± .03	.70± .04	.59± .05	.16± .08
Do	1915	.64± .08	.38± .12	.57± .10	.75± .06	.48± .11	.07± .14
Sorghum, Dakota Amber	1914	.56± .06	.72± .04	.81± .03	.74± .04	.52± .06	.27± .08
Sudan grass (in inclosure)	1914	.55± .06	.84± .03	.83± .03	.93± .01	.73± .04	.52± .07
Do	1915	.64± .08	.28± .12	.64± .08	.75± .06	.37± .11	.04± .13
Sudan grass (in open)	1914	.52± .07	.81± .03	.85± .03	.82± .03	.60± .06	.32± .08
Corn, Northwestern Dent	1914	.80± .04	.71± .04	.81± .03	.79± .03	.69± .05	.28± .08
Corn, Algeria	1914	.62± .06	.79± .04	.88± .02	.85± .03	.75± .04	.33± .09
Mean of 1914 coefficients		.60	.72	.82	.78	.66	.29
Mean of all coefficients		60	.64	.77	.77	.60	.23
Square of mean of 1914 coefficients		.36	.52	.67	.61	.44	.08
Square of mean of all coefficients		.36	.41	.59	.59	.36	.05

The dependence of transpiration on the various factors, as expressed by the squares of the mean correlation coefficients, are as follows: Radiation, 36 per cent; temperature, 41 per cent; wet-bulb depression, 59 per cent; and wind, 5 per cent. The association of transpiration with evaporation from the shallow tank is 59 per cent, and from the deep tank 36 per cent. As in the case of the cereals, the evaporation from the shallow tank and the integrated wet-bulb depression show the same degree of association with the transpiration.

LEGUMES.—The correlations of the transpiration of the legumes (Table XXIII) with the various climatic factors and with evaporation discloses the same relationships appearing in the other groups.[1] Wet-bulb depression and evaporation from the shallow tank gave, as before, the highest coefficients. Radiation, temperature, and evaporation (deep tank) show a somewhat lower correlation, while wind again shows a low correlation.

The correlation of the transpiration with the intensity of the physical factors of the legumes is lower than either group considered above, but the different factors stand in about the same relationship. The dependence of transpiration on the several climatic factors and the association

[1] The correlation coefficients between the transpiration of amaranthus and the weather factors were as follows:

	1914	1915
With radiation	0.40±0.09	0.69±0.07
With temperature	.45± .08	.60± .09
With wet-bulb depression	.60± .07	.80± .05
With evaporation (shallow tank)	.56± .06	.58± .09
With evaporation (deep tank)	.47± .08	.62± .08
With wind velocity	.04± .10	.15± .14

of transpiration with evaporation as shown by the square of the mean correlation coefficients is as follows: Evaporation (shallow tank), 55 per cent; wet-bulb depression, 50 per cent; evaporation (deep tank), 35 per cent; temperature, 32 per cent; radiation, 27 per cent; and wind, 6 per cent.

TABLE XXIII.—*Correlation of transpiration of legumes with intensity of weather factors and with evaporation*

Plant.	Year.	Radiation.	Temperature.	Wet-bulb depression.	Evaporation.		Wind.
					Shallow tank.	Deep tank.	
Cowpea	1914	0.56±0.06	0.72±0.04	0.82±0.03	0.79±0.03	0.73±0.04	0.31±0.08
Do	1915	.75± .05	.38± .09	.69± .06	.82± .04	.57± .07	.04± .11
Lupine	1914	.58± .06	.63± .06	.75± .04	.76± .04	.68± .05	.36± .08
Alfalfa, E23-20-52	1914	.40± .06	.48± .06	.67± .04	.67± .04	.54± .05	.28± .07
Alfalfa, 162-98A	1914	.42± .06	.45± .06	.67± .04	.69± .04	.55± .05	.25± .07
Do	1915	.52± .07	.74± .04	.65± .05	.78± .04	.61± .06	.19± .09
Alfalfa, E23 (in inclosure)	1914	.43± .06	.50± .06	.70± .04	.74± .03	.56± .05	.32± .07
Do	1915	.52± .06	.71± .04	.66± .05	.69± .06	.50± .06	.18± .08
Alfalfa, E23 (in open)	1914	.47± .06	.55± .05	.76± .03	.72± .04	.58± .05	.31± .07
Mean of 1914 coefficients		.48	.56	.73	.73	.61	.31
Mean of all coefficients		.52	.57	.71	.74	.59	.25
Square of mean of 1914 coefficients		.23	.31	.53	.53	.37	.10
Square of mean of all coefficients		.27	.32	.50	.55	.35	.06

CORRELATION OF DAILY TRANSPIRATION OF ALL CROPS, CONSIDERED AS A SINGLE POPULATION, WITH THE INTENSITY OF WEATHER FACTORS

The degree of correlation of the various weather factors with the transpiration ratios of all the plants considered as one population has also been determined. The coefficients for the two years are given in Table XXIV, together with their squares. They show the same relationships as in the crop groups. The mean values of the squares of the correlation coefficients for the two years are as follows: Wet-bulb depression, 0.55; temperature, 0.38; radiation, 0.30; wind, 0.04; evaporation (shallow tank), 0.56; and evaporation (deep tank), 0.33.

TABLE XXIV.—*Correlation of transpiration of all crops, considered as a single population, with weather factors, based on logarithmic differences of consecutive days*

Weather factor.	1914		1915	
	Correlation coefficient.	Square of correlation coefficient.	Correlation coefficient.	Square of correlation coefficient.
1. Radiation	0.50±0.01	0.25	0.59±0.02	0.35
2. Temperature	.64± .01	.41	.59± .01	.35
3. Wet-bulb depression	.79± .01	.62	.69± .01	.48
4. Evaporation (shallow tank)	.72± .01	.52	.75± .01	.59
5. Evaporation (deep tank)	.63± .01	.40	.51± .02	.26
6. Wind velocity	.26± .02	.07	.14± .02	.02

A SECOND METHOD OF CORRECTING FOR THE CHANGE IN THE TRANSPIRATION COEFFICIENT IN DETERMINING THE CORRELATION OF TRANSPIRATION WITH WEATHER FACTORS

The effect of the change in the transpiration coefficient can also be largely avoided in correlation studies involving transpiration through recourse to the transpiration-evaporation ratio. If transpiration and evaporation show the same hourly response to weather factors, the transpiration-evaporation graph for the season would represent the progressive changes in the transpiration coefficient. But since the transpiration-evaporation graph always presents irregularities owing to experimental errors and to the fact that a one-to-one correspondence does not exist between the two quantities, it is necessary to make use of a smoothed curve through the observations in applying this reduction. The ratios for each day of the ordinate of the smoothed graph to the maximum ordinate will give the transpiration coefficient for each day in terms of the maximum.[1] If, now, we divide the transpiration observed on each day by the corresponding ratio of the ordinates, we obtain a series of daily transpiration quantities which are independent of the size and degree of maturity of the plant, but which still retain all the daily fluctuations due to environment. These corrected transpiration quantities can, therefore, be used directly in studying the correlation of transpiration with any given environmental factor.

In the case of Kubanka wheat, the smoothed transpiration-evaporation ratio was represented by two straight lines meeting in a maximum on July 12. The daily transpiration of Kubanka has been corrected on this basis for the march in the transpiration coefficient and the correlation with the various physical factors determined. The results of the computations are given in Table XXV. For comparison, the correlation coefficients based on the first method (ratios of values on consecutive days) have also been included in Table XXV. It will be seen that the coefficients determined by the first method are slightly higher than those based on the second method. This is to be expected, since the second method assumes a one-to-one correspondence between transpiration and evaporation, so that departures from such a relationship distort the computed transpiration. The difference in the coefficients computed by the two methods is, however, usually less than its probable

[1] The daily ratios of the observed transpiration and evaporation can not be used directly, as the following discussion will show:

Let $\frac{T_t}{E_t}$ represent the ratio of the transpiration to evaporation at time t, and $\frac{T\max}{E\max}=k$, represent the maximum ratio.

The daily ratio at time t expressed in terms of the maximum is then $\frac{T_t}{kE_t}$.

If, now, we divide the observed transpiration T_t by this ratio in order to free the daily observations from the effect of the change in the transpiration coefficient, we obtain as the quotient simply kE_t. In other words, the observed transpiration is dropped from consideration, and the specific assumption is made that transpiration is proportional to evaporation. The use of the smoothed graph avoids this assumption so far as the transpiration of any given day is concerned.

error, and the correlations are substantially in accord with those previously determined.

TABLE XXV.—*Comparison of correlations obtained by the two methods of correcting for the march in the transpiration coefficient, Kubanka wheat, 1914*

Factor	First method	Second method
Transpiration and evaporation:		
Shallow tank	0.85±0.03	0.83±0.03
Deep tank	.76± .04	.67± .06
Transpiration and radiation	.64± .06	.77± .03
Transpiration and temperature	.72± .05	.62± .07
Transpiration and wet-bulb depression	.88± .02	.79± .04
Transpiration and wind velocity	.26± .09	.27± .10

SUMMARY

The transpiration studies included in this paper were made at Akron, Colo., during the summers of 1914 and 1915.

The plants were grown in large pots (115 kgm. of soil) and sealed to prevent evaporation from the soil surface.

The pots were weighed each morning before the transpiration response to sunlight had set in.

Six pots of each crop were used in the determinations, and were weighed to 0.1 kgm.

Twenty-two crops (132 pots) were included in the 1914 measurement and 23 crops (138 pots) in 1915.

Continuous automatic records were also obtained of air temperature, solar radiation, wet-bulb depression, wind velocity, evaporation from a shallow tank, and evaporation from a deep tank.

The climatic conditions were exceptionally uniform throughout the season of 1914. The summer of 1915 was unusually rainy.

During a 10-day period of maximum transpiration the annual crops lost about one-fourth of the total water lost during the season. The alfalfas lost during this period almost one-half of the total water transpired in the production of the second crop.

During a 10-day period of maximum transpiration the daily loss of water from the small grains ranged from 12 to 16 times the dry weight of the crop; millets, corn, and sorghums, 6 to 9 times; and alfalfas, 36 to 56 times the dry weight harvested. On the basis of a production of 1 ton of dry matter per acre, this would correspond in the case of the small grains to a daily loss of 0.11 to 0.14 acre-inch of water; corn, millet, and sorghum, 0.05 to 0.08 acre-inch; and alfalfas, 0.32 to 0.49 acre-inch.

The loss of water from the small grains during the period of maximum transpiration amounted to 1.5 kgm. per square meter of plant surface per day; Sudan grass, 0.8 kgm; and alfalfa, 1.6 kgm. This is from 5 to 14 per cent of the loss during the same period from a free water surface of equal area.

The transpiration of the different crop plants per unit area of plant surface shows less variation than the transpiration per unit weight of dry matter. In other words, the greater efficiency shown by certain plants in the use of water appears to be due more to a reduction in plant surface than to a reduction in transpiration per unit area of surface. The direct solar radiation received by the plants at Akron is usually not sufficient to account for the observed transpiration during the midday hours. In some of the small grains the energy dissipated through transpiration is twice the amount received directly from the sun.

The march of the transpiration due to changes in the plant alone (change in the transpiration coefficient) may be expressed by the ratio of the daily transpiration to the daily evaporation if we assume the latter to constitute a perfect summation of the weather conditions determining transpiration. The transpiration of the annual crop plants (aside from fluctuations due to weather) rises to a maximum a little beyond the middle of the growth period and then decreases until the plants are harvested. Perennial forage crops such as alfalfa increase steadily in transpiration to a maximum at or near the time of cutting. Various crops show their individuality by departing more or less from these types.

The transpiration coefficient of many of the crops increases exponentially during the early stages of growth. Sudan grass, for example, doubled its transpiration coefficient every four days during the early growth period. Alfalfa throughout practically the whole period between cuttings doubled its transpiration every eight days.

The relative change in the transpiration coefficients of two crops may be determined by taking the ratio of the transpiration of the two crops day by day without the necessity of correcting for changes in weather.

The correlation has been determined between the various physical factors of environment and the transpiration of the different crops, considered both individually and as one population. The correlation coefficients in the latter case for the season of 1914 are as follows:

Transpiration with radiation, 0.50 ± 0.01; with temperature, 0.64 ± 0.01; with wet-bulb depression, 0.79 ± 0.01; with evaporation (shallow tank), 0.72 ± 0.01; with evaporation (deep tank), 0.63 ± 0.01; and with wind velocity, 0.26 ± 0.01.

The small grains show individually a markedly higher correlation between transpiration and the intensity of the various physical factors than was observed when all the crops were combined in one population. The mean correlation coefficients for the small grains (1914) are as follows: Transpiration with radiation, 0.65; with temperature, 0.71; with wet-bulb depression, 0.88; with evaporation (shallow tank), 0.87; with evaporation (deep tank), 0.75; with wind velocity, 0.22.

The corn, sorghum, and millet group and the legume group show a somewhat lower correlation between transpiration and the intensity of the physical factors of environment. The plants in the various groups,

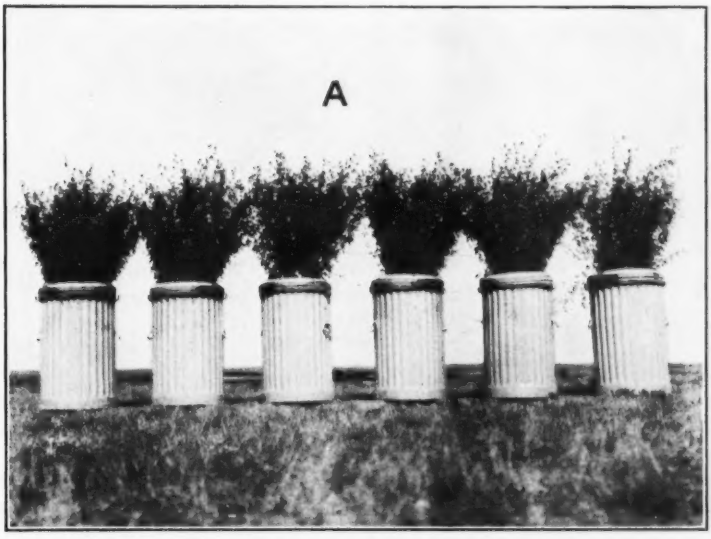
however, show the same relative dependence of transpiration upon the physical factors. Wet-bulb depression and evaporation (shallow tank) exhibit the highest correlation with transpiration in all cases, while wind velocity is correlated with transpiration to a very slight extent at Akron.

The degree of dependence of transpiration of the small grains in 1914 upon radiation, temperature, wet-bulb depression and wind velocity, considered as independent causative factors, as shown by the squares of the correlation coefficients is as follows: Wet-bulb depression, 0.77; temperature, 0.50; radiation, 0.42; and wind velocity, 0.05. Since the sum of these squares exceeds unity, the physical factors are evidently intercorrelated. The association of transpiration of the small grains with evaporation (shallow tank) is 0.76, or the same as with wet-bulb depression.

PLATE 5

Fig. A.—Six pots of alfalfa used in transpiration measurements. The daily transpiration of each pot of plants was determined independently, and the mean of the six determinations used as the daily transpiration of the crop.

Fig. B.—Six pots of corn used in transpiration studies.


A

B

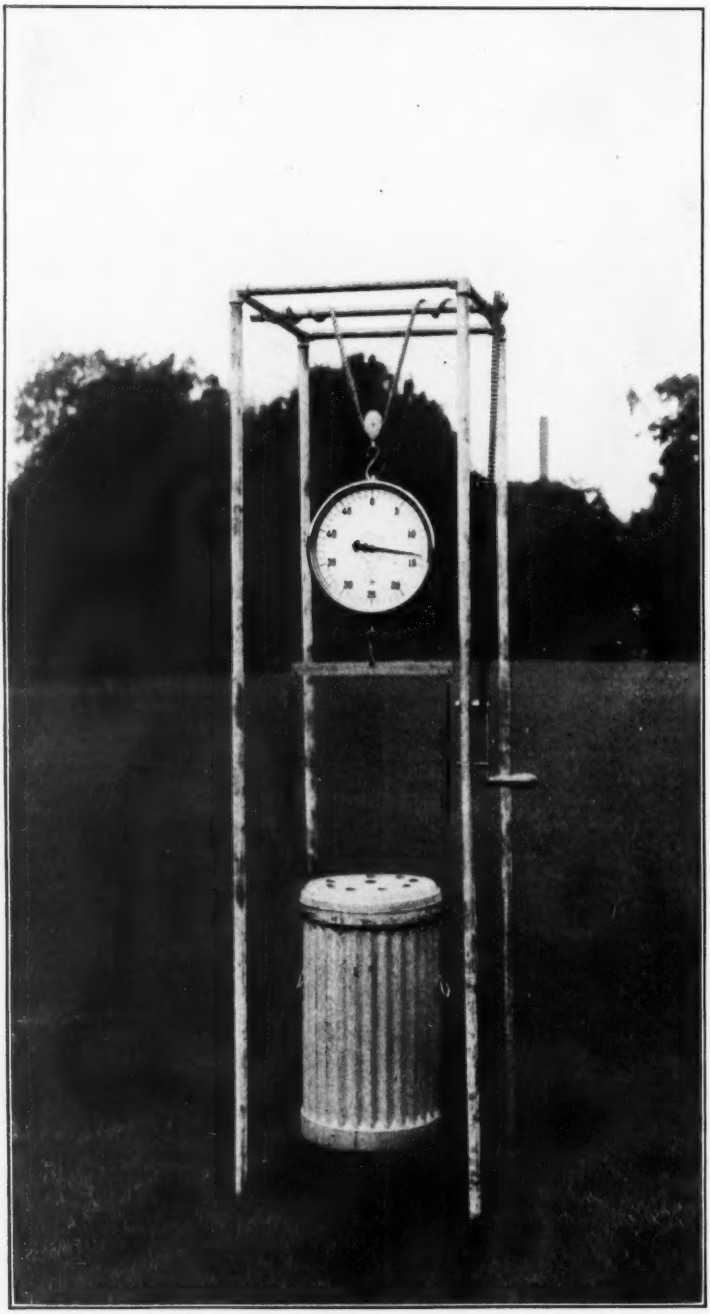


PLATE 6

The type of spring balance and lifting device used in the transpiration measurements. The balance was checked against a standard weight of 130 kgm. each morning before and after the weighings. The pot is 16 inches in diameter and 26 inches high. The cover is provided with 1-inch holes, as used with alfalfa and sorghum. The center hole is used for watering.